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The Bondage of TIME & SPACE

How Fast is Our Universe Expanding?

Raising Your Kids to Be Astronomers

Chasing Planets that Don't Exist

Build-It-Yourself Dobsonian Kit

LX50

Advanced technology at the most affordable prices *ever.*

■ **Battery-Powered, Completely Cordless Operation!** Meade LX50 models operate for more than 50 hours from six AA-size batteries inserted through the telescope's control panel. Or use the standard-equipment 25 ft. cord to power the telescope directly from any auto cigarette lighter plug.

■ **Standard-Equipment Declination Motor and Hand Controller:** Plug the hand controller into the LX50 control panel and you're ready for full dual-axis drive capability at any of 4 photo-guide or microslew speeds: 2x, 8x, 16x, or 32x, plus quartz-controlled sidereal-rate tracking in R.A. Switch speeds instantly using the speed-control button on the hand controller. Dual-axis drive rate is indicated by a red LED.

■ **Multi-Function Control Panel:** Includes connectors for CCD autoguiders; for the standard-equipment Declination motor; and for the optional Magellan II Computer-Corrector *(below)*. A North-South switch permits telescope operation anywhere in the world.

■ **Super Multi-Coated Optics:** The exact same EMC super multi-coated optical tube assemblies included with Meade LX200 models.

■ **Massive LX200-type Fork Mounts:** Meade LX50 mounts are manufactured of the same virgin aluminum castings as Meade LX200 Schmidt-Cassegrains. Massive, rigid mountings that include the Meade LX worm-gear drive system with low periodic error for advanced photographic or CCD imaging applications. *No competing mid-priced equatorial mountings even come close.*

SPECIFICATIONS: 7", 8", and 10" LX50's—Each complete telescope includes 8" or 10" f/10 Schmidt-Cassegrain or 7" f/15 Maksutov-Cassegrain optical tube assembly with EMC super multi-coatings; heavy-duty LX200-type fork mount; 5.75" LX worm gear system in R.A.; multi-function control panel; DC servo Declination motor; manual and electric slow-motion controls on both axes; setting circles on both axes; keypad hand controller; 4-speed drive controls on both axes; battery compartment accepting six (user-supplied) AA-size batteries; 25 ft. power cord for telescope operation from 12v. auto cigarette lighter plug; 6 x 30mm (7" and 8" models) or 8 x 50mm (10") viewfinder; 1.25" diagonal prism; MA25mm multi-coated eyepiece (1.25"); standard equatorial wedge with elevation scale, bubble level, and azimuth control; complete operating instructions.

8" LX50 Schmidt-Cassegrain	**$1395.**
10" LX50 Schmidt-Cassegrain	**1695.**
7" LX50 Maksutov-Cassegrain	**1795.**
Variable-Height Field Tripod	**295.**
7" Maksutov-Cassegrain Tube Ass'y	**1295.**

Packing and shipping in the 48 states: 8"—$105; 10"—$145; 7"—$125; 7" Tube Assembly—$65.

Meade Magellan™ II Computer-Corrector for LX50 Telescopes: Plug the Magellan II into the control panel of your LX50 and enjoy an incredible range of advanced capabilities. ■ Fast manual slewing to any object, either from input RA and Dec or from the 12,218-object database. ■ High-resolution 4096-pulse encoders (5.3 arc-minute precision), concealed in special LX50 encoder compartments. ■ Large 32-character, red-backlighted display. ■ Quick 2-star alignment. ■ Four-speed (2x, 8x, 16x, 32x sidereal) dual-axis drive corrector/microslewing system.

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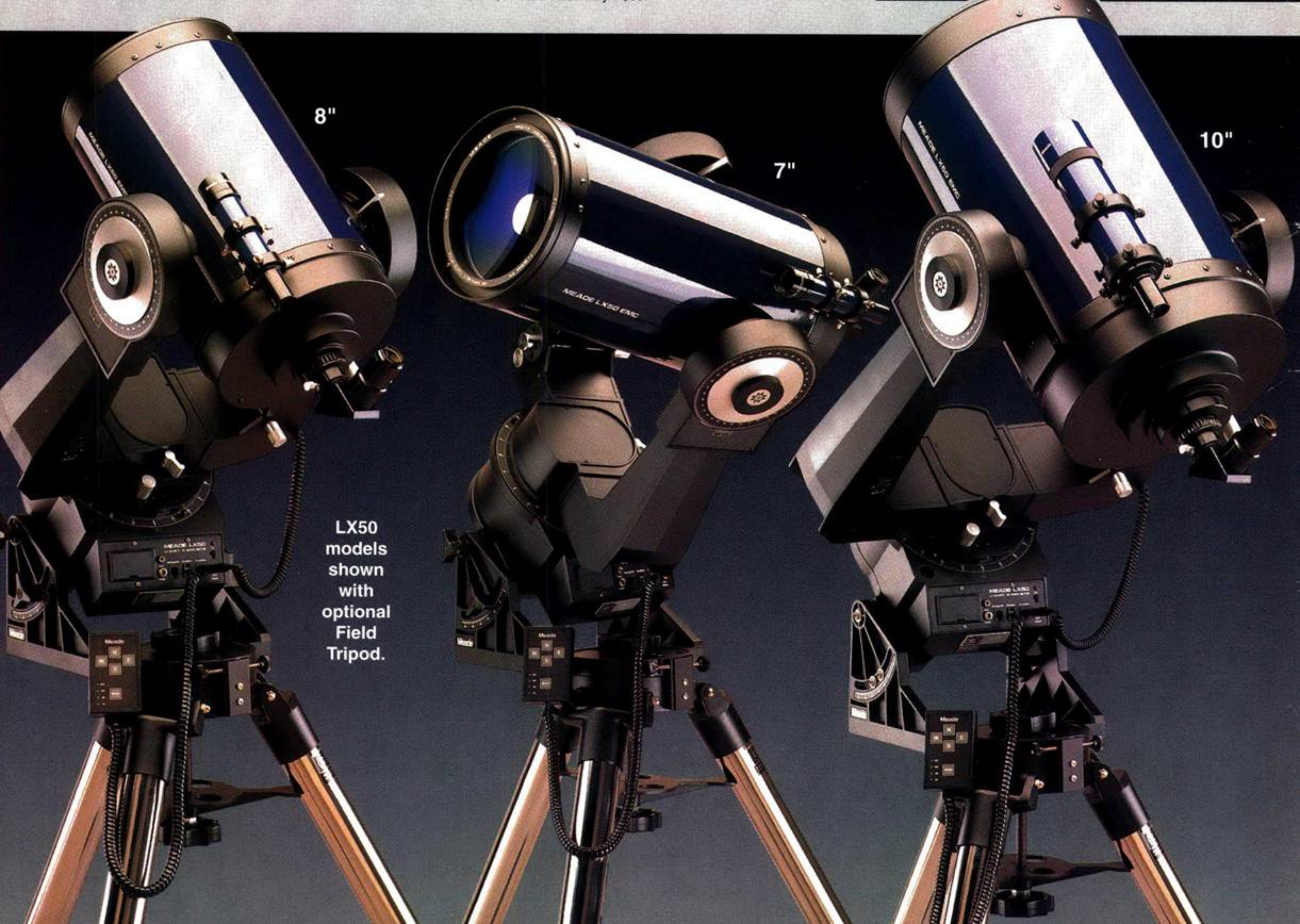
only $495!

#2024: Magellan II for LX50's—Includes Magellan II hand controller *(right)*; encoders for both axes; all required mounting hardware. Installs to any LX50 in minutes. **$495.** + $15 packing and shipping in the 48 states.



LX50 models shown with optional Field Tripod.

The largest-selling serious telescopes in the world.

LX200

In virtually every country in the world where serious telescopes are sold, more Meade LX200's are sold than all competing models combined. Consider these *standard-equipment* specifications:

- **Superb Optics:** LX200 diffraction-limited imaging capabilities are a legend in the industry; we regularly receive reports stating that optical performance approaches that of a fine *ED* apochromatic lens.
- **Automatic GO TO Capability:** Meade LX200's are *the only commercial telescopes ever manufactured* that automatically GO TO any input R.A. and Dec., or to any of 64,359 objects in the onboard database, *to a precision of one arc-minute or better.*

8" LX200 Schmidt-Cassegrain	**$2795.**
10" LX200 Schmidt-Cassegrain	**3195.**
12" LX200 Schmidt-Cassegrain	**4495.**
7" LX200 Maksutov-Cassegrain	**3295.**

Packing and shipping in the 48 states: 8"—$105; 10"—$145; 12"—$215; 7"—$125.

- **Meade LX200 High-Precision Pointing™** is so precise it permits the positioning of *every* selected object on *every* commercially-available CCD chip *every* time, automatically — *a feat that no other telescope priced under $40,000 can accomplish.*
- **Permanently-Programmable Smart Drive™** routinely achieves 5 arc. sec. periodic error, an observatory standard.
- **9-Speed Dual-Axis Electronics:** Electronics that cover every possible contingency of telescope positioning—from 2x photo-guide, to 32x image centering, to 8°/sec. slewing across the sky, as well as 6 other dual-axis drive speeds in between.
- **Field Operation:** No other telescopes of such incredible capabilities transport so readily for field operation. The optional #1812 Electronic DC Adapter (a compact 4 oz. unit) allows for field powering directly from an automobile cigarette lighter plug.

SPECIFICATIONS: 7", 8", 10", and 12" LX200's—Each complete telescope includes 8" or 10" (f/6.3 or f/10) or 12" f/10 Schmidt-Cassegrain or 7" f/15 Maksutov-Cassegrain optical tube assembly with EMC super multi-coatings; heavy-duty fork mount with 4" polar ball bearing, dual-axis 5.75" worm gears, and multi-function control panel; manual and electric slow-motion controls on both axes; keypad hand controller with digital readout display, permanently programmable Smart Drive, 9-speed drive controls on both axes (7-speed on 12"), High-Precision Pointing, and GO TO controller; 64,359-object onboard celestial software library; 25 ft. power cord and adapter for telescope operation from 115v.AC; 8 x 50mm viewfinder; 1.25" diagonal prism (7", 8", 10") or 2" diagonal mirror with 1.25" adapter (12"); Series 4000 Super Plössl 26mm eyepiece; standard field tripod (7", 8", 10") or giant field tripod (12"); operating instructions.

MEADE LX200 EMC
8"
7"
10"
12"
Meade

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COVER PHOTO: Mike Bessell, Mount Stromlo and Siding Spring Observatories

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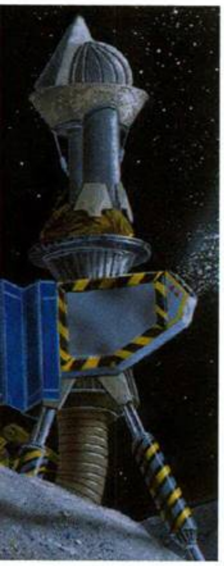

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48 Digging for Gold

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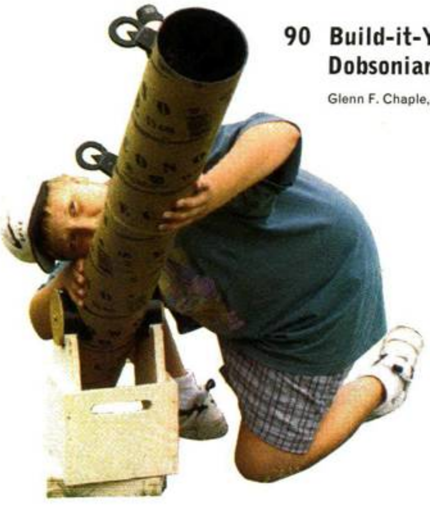

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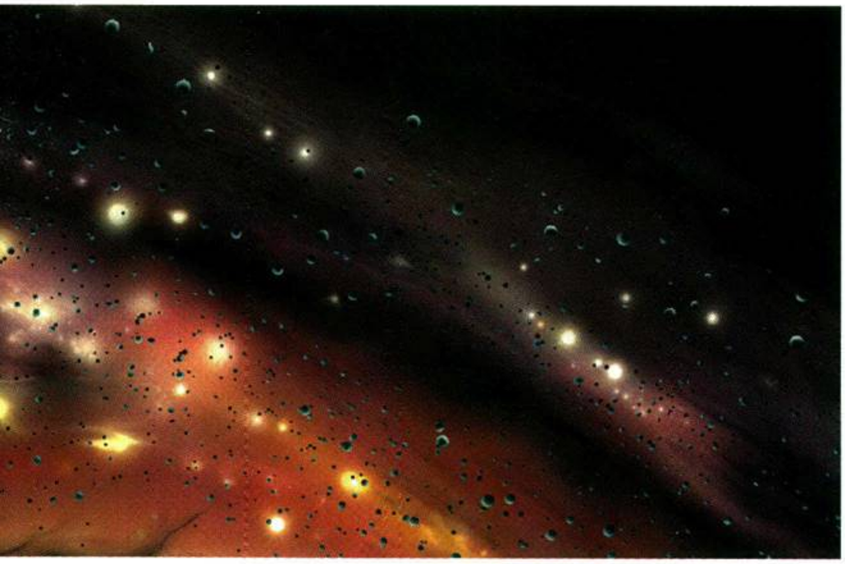

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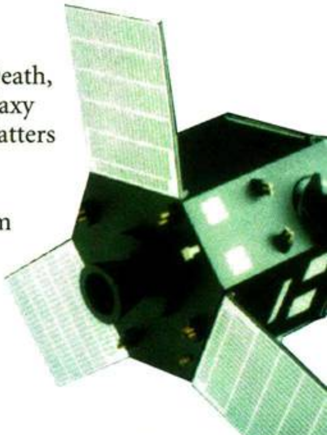

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European Space Agency

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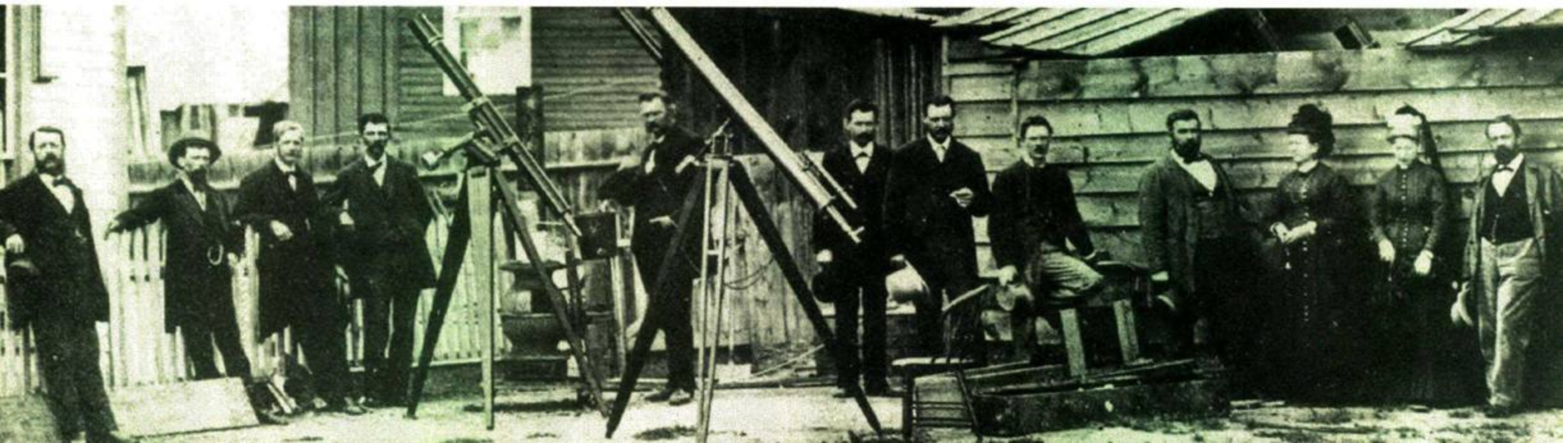
The Mary Lea Shane Archives of the Lick Observatory



BEHIND THE SCENES

BY BONNIE BILYEU GORDON

Making the Sky Clear

In this, the Christmas issue of *Astronomy*, it's appropriate, I think, to address a subject that has been profoundly missing in the magazine for many years: children. In Steve Olson's story called "Raising Astronomers" we want to draw your attention to the true future of astronomy. We want to ask you to help us find and nurture young astronomers in today's world, where most people live in cities, and their skies are not terribly inviting.

Brittany Paydock of La Petite Academy in Waukesha, Wisconsin, modeled this solar system for *Astronomy*.

In spring of this year at a science meeting, I ran into Steve, who I hadn't seen for perhaps 10 years. He could not stop talking about his children, only one of whom existed when I left town. When he learned about my move to *Astronomy*, he was quick to tell me about the sort of astronomy education his two kids are getting in their upscale Maryland neighborhood. (See solar system drawing by Sarah Olson on page 78.) But he complained that it wasn't enough and said that this was a subject close to his heart.

It's close to my heart too, and we'd both like to share one message here: Without support, certain sciences will slip away from public education completely. Without support, kids will grow into adults who know about as much of the heavens as citizens of the Middle Ages. If you don't believe this (or even if you do), take a look at Steve's evidence beginning on page 78, and see if my concern is too great. "Raising Astronomers" is a first effort in an *Astronomy* mandate for learning.

We will be looking for stories that focus on young astronomers and for projects that will awaken and warm the interests of the young — and in fact, all beginners. This is part of the mission of any true astronomy magazine (and of any single astronomy story or any single television program on the subject), and we mean to fulfill that mission here.

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90mm Maksutov-Cassegrain

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Meade ETX Astro Telescope. Shown with optional #64 Photo Adapter.

SPECIFICATIONS: ETX Astro Telescope—Includes Maksutov-Cassegrain optical tube assembly (D = 90mm, F = 1250mm, f/13.8) with EMC super multi-coatings; internal flip-mirror system for either straight-through or 90° observing position; equatorial fork mount with slow-motion controls, locks, and setting circles in R.A. and Dec; table tripod with elevation scale on center tripod leg; motor drive system with internal battery compartment accepting three (user-supplied) AA-size batteries; 8 x 21mm achromatic erect-image viewfinder; Series 4000 Super Plössl 26mm eyepiece (1.25"); operating instructions. *Net weight 9 lbs.* **$595***
(+ $20 packing and shipping in the 48 states)
*Suggested U.S. mail-order retail price.

Now you can have diffraction-limited imaging and ultraportability ...at only *$595*, *complete!*

The revolutionary Meade ETX goes anywhere with you at a moment's notice and presents the finest optical images ever made available in an ultraportable telescope.

Optical System: Manufactured at the Meade Irvine, California facility, ETX diffraction-limited optics produce images so high in contrast, brightness, and resolution that the ETX consistently outperforms telescopes of much larger apertures. **Equatorial Fork Mount:** Precise polar alignment in *seconds,* just by extending the center tripod leg to read your latitude on the inscribed scale. **Cordless Motor Drive:** The internal drive system operates from 3 AA-size batteries that power the motor drive for more than 50 hours. A North-South switch permits operation anywhere in the world. **Flip-Mirror System:** Flip the internal optical flat mirror "up" for 90° observing; flip the mirror "down" for terrestrial observing with the optional #932 45° Erecting Prism or for photography with the optional #64 Photo Adapter. **Standard accessories** include a Series 4000 Super Plössl 26mm eyepiece and 8 x 21mm erect-image viewfinder.

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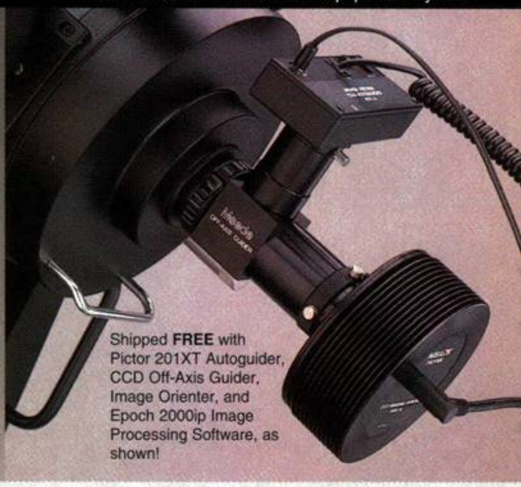
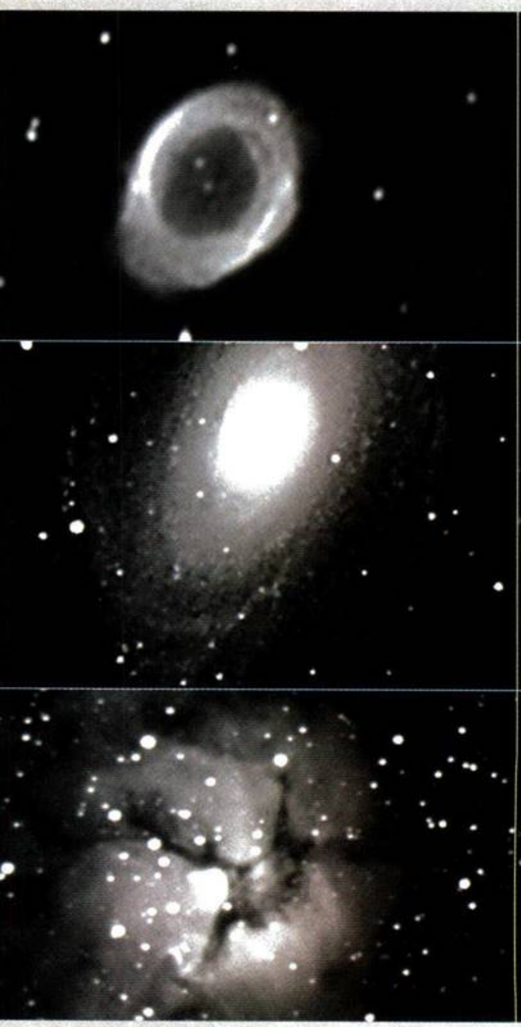
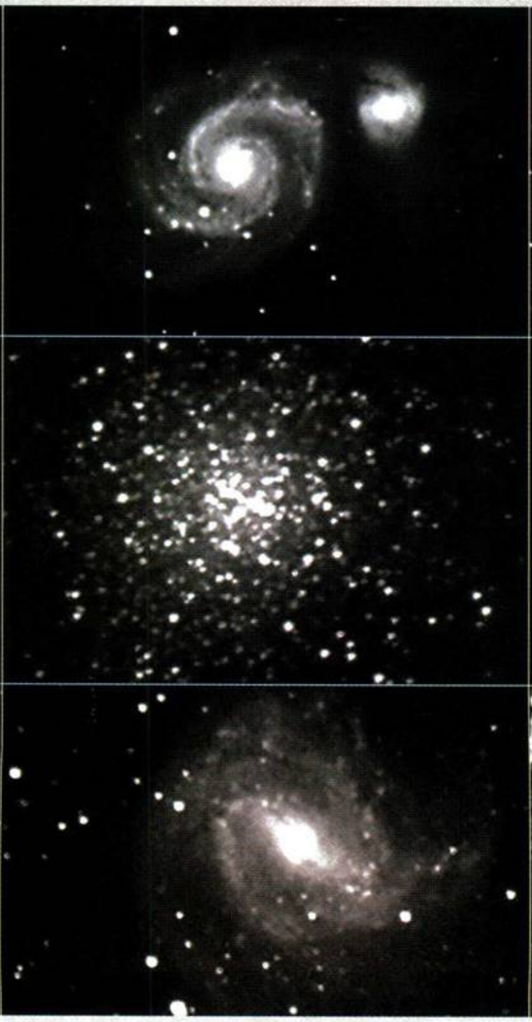


Shipped **FREE** with Pictor 201XT Autoguider, CCD Off-Axis Guider, Image Orienter, and Epoch 2000ip Image Processing Software, as shown!

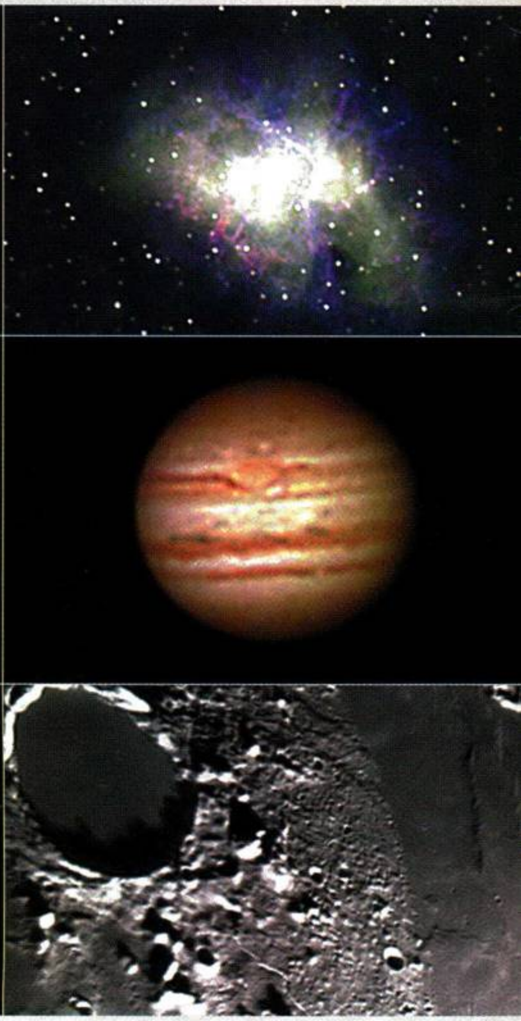
Revolutionary Meade Pictor CCD's are now the world's largest-selling autoguiders and imagers for the amateur astronomer. No other electronic imaging systems offer such an incredible range of capabilities at such amazing price levels. At only **$495** the **Pictor 208XT** produces on the PC display fine, high-resolution 8-bit images *in seconds* of the Moon and planets, or, in 2 or 3 minutes, of thousands of deep-space objects. At **$695** the **Pictor 216XT** enables advanced 16-bit imaging and is *by far* the finest autoguider/imager ever made available at under-$1000. At **$1695** the **Pictor 416XT** permits professional-level imaging capability for the amateur astronomer: an electronic camera capable of producing with amateur telescopes images of the Moon, planets, and deep-space that match or exceed the photographic images obtained with many observatory telescopes. All models are available for immediate shipment. ***For complete information on Meade CCD imaging systems write, call, or fax for your free copy of the 100-page Meade General Catalog.***



Pictor 208XT images *(top to bottom):* Ring Nebula (M57), 25" reflector, Jack Newton; Galaxy (M81) in Ursa Major, 12" LX200, Scott Roberts; Trifid Nebula (M20), 8" LX200, John Hoot.



Pictor 216XT images: Whirlpool Galaxy (M51), 12" LX200, John Hoot; Globular Cluster (M13), 25" reflector, Jack Newton; Galaxy (M83) in Hydra, 12" LX200, Scott Roberts.



Pictor 416XT images: Crab Nebula (M1), 25" reflector, Jack Newton; Jupiter, 10" LX200 with Stellar Products AO-2 seeing adapter, Dr. Donald Bruns; Moon (crater Plato), 16" f/6 reflector, Dr. Donald Parker.

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MEADE 8" LX10

All the optical performance of Meade 8" LX50 and LX200 Schmidt Cassegrains...for only *$995!*

For the serious amateur astronomer on a more limited budget, or for the more casual observer who nonetheless demands the very finest in optical performance, the Meade 8" LX10 satisfies every requirement. *No other similarly-priced 8" Schmidt-Cassegrain offers such a range of standard features* — or such a range of important options for special applications. *Standard-equipment includes:*

Super Multi-Coated Optical System: The LX10 includes the *exact same* 8" Schmidt-Cassegrain optical tube assembly as more expensive Meade 8" LX50 and LX200 models. Super multi-coatings (not available even as an *option* on competing 8" telescopes) are included with every LX10 optical system, for the highest levels of light transmission and image contrast.

Equatorial Fork Mounting: The relatively light weight, but very stable, LX10 fork mounting provides all of the rigidity required for sensitive high-power applications of the telescope, or for photographic or CCD imaging. Ball bearings on the polar axis complement the precise action of the internal worm gear system.

Cordless, DC-Powered Electronic Motor Drive: A drive system that includes an electronically-regulated DC servo motor for automatic *sidereal-rate* tracking. The drive is powered by four AA-size batteries that fit conveniently through the telescope's control panel; battery life is in excess of 50 hours.

Worm-Gear System: The LX10's 5.75"-diameter worm gear produces extremely smooth, regular motion in R.A., with low periodic error — a periodic error that permits such advanced capabilities as long-exposure astrophotography or CCD imaging.

Hand Controller: Essential for micro-guiding the telescope during long-exposure astrophotography, the LX10's pushbutton hand controller enables precise corrections in R.A. at 2x speed. With the optional electric Declination motor added to the telescope, the hand controller is functional at 2x speeds on both telescope axes. Both the standard-equipment hand controller and the optional electric Declination motor plug into the telescope's control panel.

SPECIFICATIONS: 8" Model LX10 — Includes 8" Schmidt-Cassegrain optical tube assembly with EMC super multi-coatings (D = 203mm; F = 2000mm, f/10); fork mount with setting circles, manual slow-motion controls, and locks on both axes; 5.75" LX worm gear reduction system; sidereal-rate electronically-regulated DC servo motor drive; 4-pushbutton hand controller for 2x speed corrections in R.A.; battery compartment accepting four (user-supplied) AA-size batteries (telescope may also be powered from an auto cigarette lighter plug, using optional 25 ft. cord); 6 x 30mm viewfinder; eyepiece-holder and diagonal prism (1.25"); MA25mm multi-coated eyepiece; standard equatorial wedge with elevation scale, fine elevation control, and 360° azimuth orientation capability; complete operating instructions.
$995. (+ $65 packing & shipping in the 48 states)

LX10 Field Tripod	**195.**
LX10 Electric Declination Motor System	**85.**
#2014 Magellan I Telescope Computer System for LX10, with 12,218-object database	**375.**

The 100-page Meade General Catalog is available free of charge from Meade Instruments or from authorized Meade dealers. Prices shown are suggested U.S. mail-order prices.

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Add the optional LX10 Declination Motor for dual-axis corrections at 2x.

Meade 8" LX10
Schmidt-Cassegrain Telescope, shown with standard-equipment equatorial wedge and hand controller and with optional LX10 Field Tripod.

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MEADE STARFINDER DOBSONIANS

No other competing Dobsonians include this listing of *standard-equipment* features:

Primary and Secondary Mirrors of Low-Expansion Pyrex® Glass: Unlike the plate glass optics of other Dobsonians that can become thermally unstable, all Meade Dobsonian optics are made of Grade-A fine-annealed Pyrex glass — the exact same professional-quality optics used on Meade Starfinder Equatorials.

Rigid, Durable, Beautiful Dobsonian Mountings, manufactured of cabinet-quality materials, provide extremely smooth motions of the telescope in both altitude and azimuth. Both telescope axes ride on zero-backlash Teflon/Nylon bearings, facilitating the quick location and easy tracking of celestial objects.

Full-Size 1.25" Rack-and-Pinion Focuser: For smooth, precise focusing of the image without wobble or backlash. Focus travel is 2.6"; accepts 1.25" eyepieces.

4-Vane Steel Secondary Mirror System: Permits locked-in support and precise centration and alignment of the secondary mirror.

Multi-Coated MA25mm Eyepiece (1.25"): The Meade Modified Achromatic 25mm eyepiece yields sharp, high-resolution imaging to the field edge.

5 x 24mm Viewfinder: Included with all Starfinder Dobsonian models for quick object-location in the main telescope. With crosshair eyepiece and 2-ring bracket.

Optical Tubes: Starfinder Dobsonians include the same strong, spiral-wound Sonotube™ optical tubes used on Starfinder Equatorials *(right),* tubes with excellent insulating characteristics that reduce internal thermal currents to an absolute minimum.

Performance! *Meade Starfinder Dobsonians and Equatorials are the largest-selling Newtonian reflectors of their apertures in the world.* Every Starfinder model opens up the skies to an extremely wide range of serious visual observing; all 110 Messier objects, thousands of NGC objects — nebulae, galaxies, star clusters, in all their variations of form, color, and extent, as well as the Moon and planets in stunning high-resolution detail. Starfinder Dobsonians are telescopes for visual observing; motor-driven Starfinder Equatorials may be used, in addition, for lunar and planetary photography, and even for limited deep-space photography.

Packing & UPS Shipping Charges to any address in the 48 states: 6"—$39; 8"—$49; 10"—$69; 12.5"—$79; 16"—$45 packing, shipped truck freight collect.

Dobsonian Deluxe Accessory Package only $49.95!

Outfit your Meade Dobsonian with all of the most popular accessories for advanced observing. At the time you order any Dobsonian model, specify the following Deluxe Accessory Package for your telescope, in place of the standard-equipment focuser, viewfinder, and eyepiece, ***for a total of only $49.95 additional:***

1 - **Meade #77 2" Giant Rack-and-Pinion Focuser,** with machined aluminum eyepiece-holders for both 2" and 1.25" eyepieces; includes drawtube lock and 2.6" focuser travel. *(reg. $59.95)*

1 - **Meade #637 6 x 30mm Achromatic Viewfinder,** with wide 7° field; 2-ring metal bracket. *(reg. $49.95)*

3 - **Meade MA9mm, 12mm, and 25mm** multi-coated eyepieces, 1.25" barrel — eyepieces for the full range of lunar, planetary, and deep-space observing. *(reg. $37.95 each)*

Purchased separately, the Deluxe Accessory Package sells for $223.75!

Meade Magellan I Telescope Computer System

Attach the optional Magellan I Telescope Computer System to your Starfinder Dobsonian and finding any of 12,218 celestial objects, or *any* object of known R.A. and Dec., is almost as easy as pointing the telescope! Magellan I's database includes the following objects:

7,840	NGC objects; the complete NGC catalog
4,093	IC objects from the Index Catalog
125	user-defined objects
110	Messier objects; the complete catalog
42	alignment stars for the Magellan system
8	major planets, from Mercury to Pluto
12,218	objects, total

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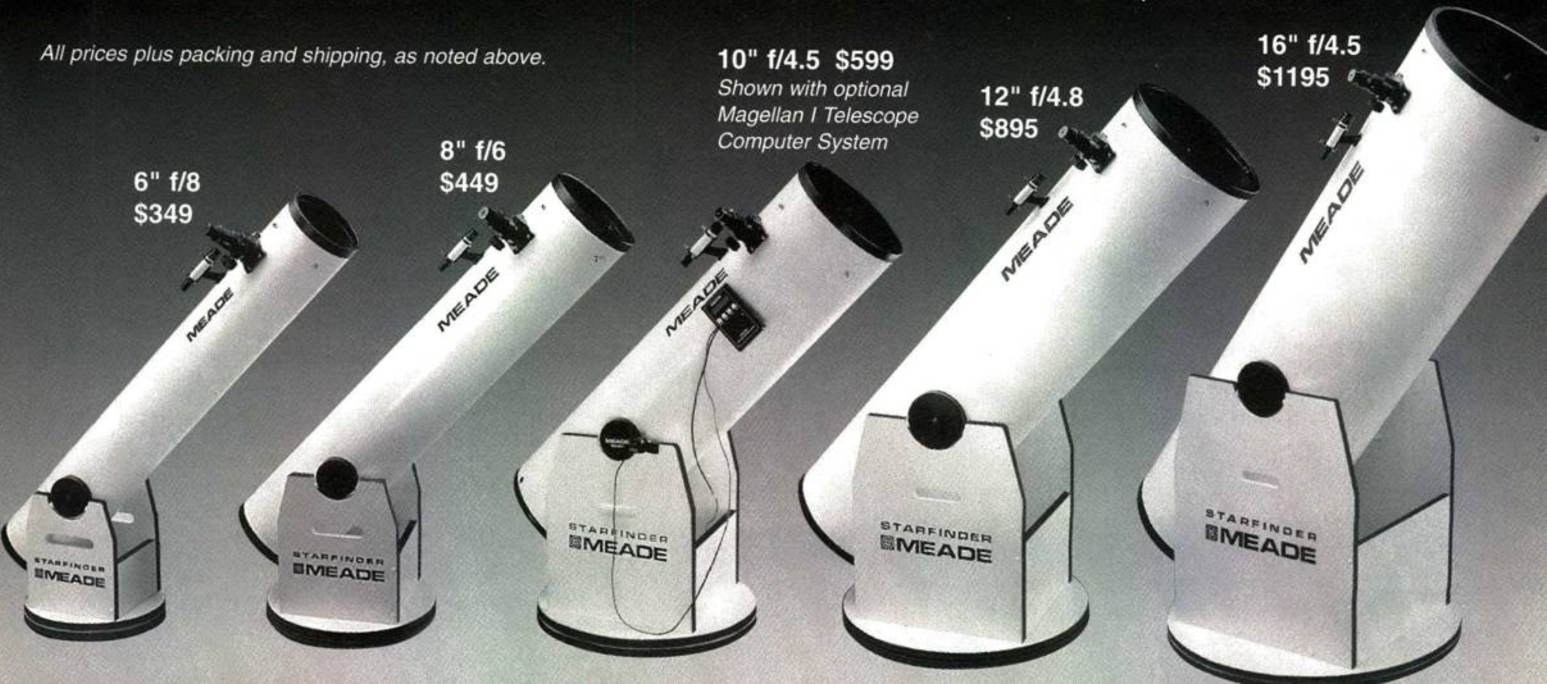
MAGELLAN I
TELESCOPE COMPUTER SYSTEM

Magellan I is supplied *complete* with control/display unit (4" x 5" x 1.25"); premium-grade, high-resolution encoders for each telescope axis (encoder precision is 5.3 arc minutes); RS-232 serial interface; bracket for placement of the controller on the telescope tube; and attachment hardware. Just add the user-supplied 9v. transistor radio battery, and Magellan I is ready to use. First-time installation is quick and simple.

#2010: for Meade Starfinder Dobsonian
6", 8", 10", 12.5", or 16" . . . . $295.
Packing & shipping in the 48 states—$15.

STARFINDER DOBSONIAN TELESCOPES ***Shown with standard-equipment 5 x 24mm viewfinder and 1.25" rack-and-pinion focuser.***

All prices plus packing and shipping, as noted above.



6" f/8
$349

8" f/6
$449

10" f/4.5 $599
Shown with optional Magellan I Telescope Computer System

12" f/4.8
$895

16" f/4.5
$1195

MEADE
STARFINDER EQUATORIALS

Special Eyepiece Offer! At the time you order any Meade Starfinder Equatorial telescope, you can buy 2 additional multi-coated eyepieces, MA9mm and 12mm, ***for a total of $29.95!*** *Purchased separately, the 2 eyepieces sell for $75.90.*

DC-powered drive systems for fully automatic tracking, and a wide range of standard-equipment features:

Professional-Grade Optical System: Includes hand-figured, parabolic primary mirror and elliptical flat secondary, both of Grade-A Pyrex glass. Optics are multi-coated and meet the theoretical limits of resolution.

Precision Equatorial Mount: Manufactured of machined aluminum to tolerances of .001" or better, with 4"-dia. pier and die-cast tripod legs for rock-solid support of the optical tube. Moves effortlessly from object to object on precision bearing surfaces. Polar and Dec. shafts are 1" solid steel. Setting circles on both axes.

Battery-Powered Cordless Drive System! Provides fully automatic tracking of celestial objects. Operates for more than 50 hours from 6 (user-supplied) AA-size batteries. Control panel also permits powering the telescope from 12v. auto cigarette lighter plug, using optional 25 ft. cord.

2" Giant Focuser: Meade #77 2" giant rack-and-pinion focuser is included as standard equipment, with eyepiece-holders for both 2" and 1.25" eyepieces.

Accessories and Components: #637 6 x 30mm viewfinder with wide 7° field; multi-coated MA25mm eyepiece (1.25"); strong, durable, spiral-wound optical tube with attractive white finish.

Starfinder Equatorial 16: Includes equatorial mounting with 1.5" steel shafts, Sealmaster ball bearings, 6" dia. pier, and 6 x AA-size battery-powered worm gear drive; 8 x 50mm viewfinder; #77 2" giant focuser.

Packing & UPS Shipping Charges to any address in the 48 states: 6"—$65; 8"—$75; 10"—$90; 16"—$55 packing, shipped truck freight collect.

Meade Magellan Telescope Computer Systems

MEADE
ENTER
MODE
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NEXT
OK
MAGELLAN I
TELESCOPE COMPUTER SYSTEM

Magellan I: Use the Magellan I computer to manually slew the telescope quickly to any of 12,218 database objects, or to any object of known R.A. and Dec. Specifications and object database are identical to Magellan I for Starfinder Dobsonians *(see facing page).*

#2011: **for Meade (DC-powered) Starfinder Equatorial 6", 8", or 10" . . . . $295.**
#2012: **for Meade (DC-powered) Starfinder Equatorial 16" . . . . 295.**

MEADE
MAGELLAN II
W
N
E
S

Magellan II Computer-Corrector: Plug the Magellan II into the control panel of your Meade Starfinder Equatorial and you have all the capabilities of the Magellan I, above, including 12,218-object database, *plus* a 4-speed (2x, 8x, 16x, 32x), dual-axis, drive corrector/microslewing system.

#2018: **for (DC-powered) Starfinder Equatorial 6", 8", 10" . . 495.**
#2019: **for (DC-powered) Starfinder Equatorial 16". . . . . 595.**

Packing & shipping in the 48 states: Magellan I–$15, Magellan II–$20.

The fullest exposition of Meade astronomical telescopes, CCD imagers, and telescope accessories is contained in the 100-page Meade General Catalog.

Write, call, or fax Meade Instruments for your free copy!

To Order: Contact your authorized Meade Advanced Products Mail-Order Dealer, below. Prices shown are suggested U.S.A. mail-order retail prices.

ASTRONOMICS, Norman, OK.
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FOCUS CAMERA, Brooklyn, NY.
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OCEANSIDE PHOTO & TELESCOPE, Oceanside, CA.
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POCONO MOUNTAIN OPTICS, Moscow, PA.
Orders: 800-569-4323; Info.: 717-842-1500.

RIVERS CAMERA, Dover, NH.
Orders: 800-245-7963; Info.: 603-742-4888.

SHUTAN CAMERA & VIDEO, Chicago, IL.
Orders & Info.: 800-621-2248; IL: 312-332-2000.

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EFSTONSCIENCE, Toronto, Ontario.
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KHAN SCOPE CENTRE, Toronto, Ontario.
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FAX: (714) 451-1460 ☐ *www.meade.com*

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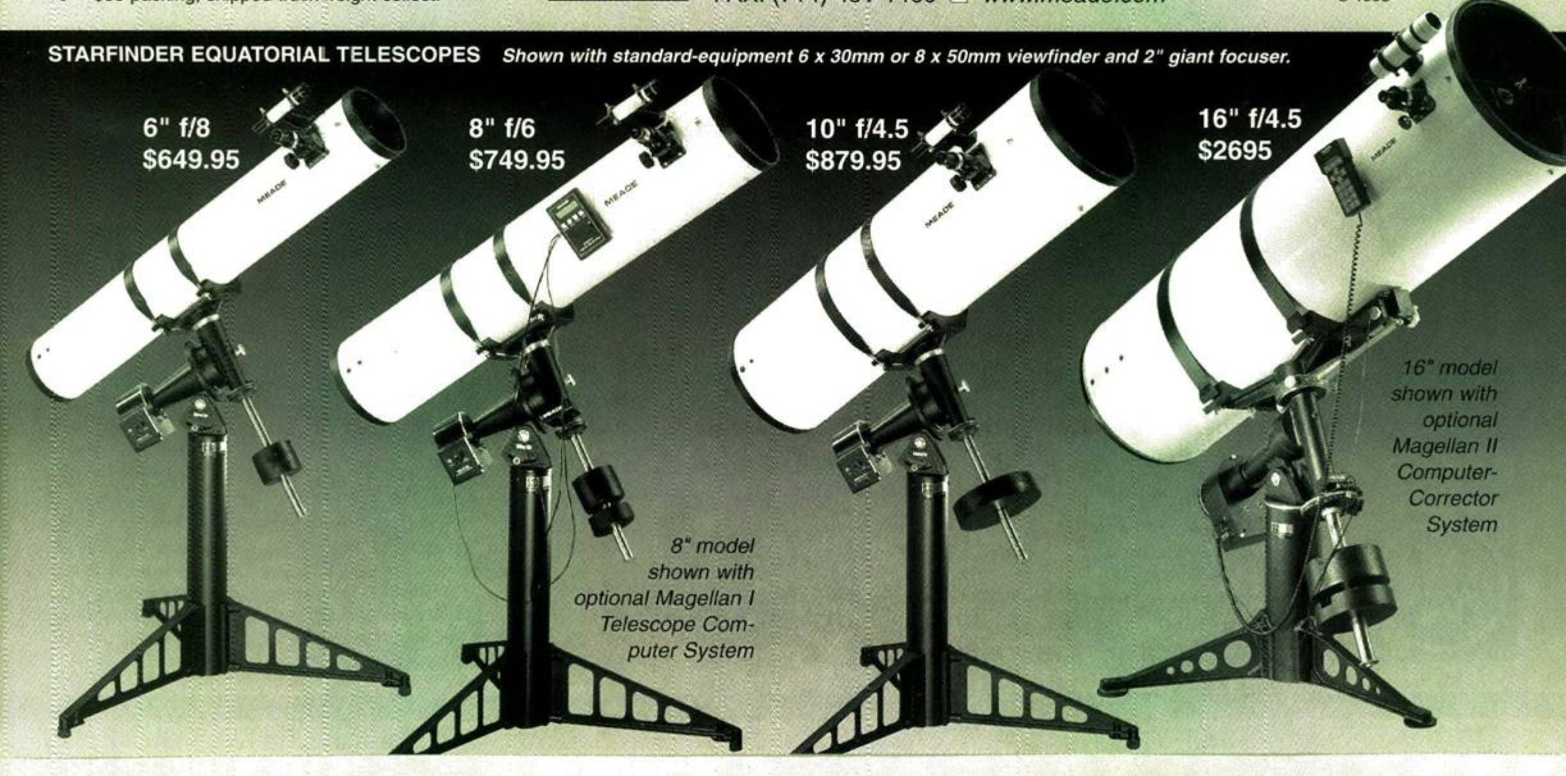
STARFINDER EQUATORIAL TELESCOPES ***Shown with standard-equipment 6 x 30mm or 8 x 50mm viewfinder and 2" giant focuser.***



6" f/8
$649.95

8" f/6
$749.95

10" f/4.5
$879.95

16" f/4.5
$2695

8" model shown with optional Magellan I Telescope Computer System

16" model shown with optional Magellan II Computer-Corrector System

MEADE
MEADE LX200

16" LX200

Professional instrumentation for the demanding school, college, or university research program—or as the ultimate personal telescope for the advanced amateur.

Professional-grade 16" f/10 Schmidt-Cassegrain optical system meets or exceeds advanced requirements; includes BK7 correcting plate with EMC super multi-coatings for high UV transmission. ■ **Massive one-piece fork mount** permits substantial auxiliary equipment to be piggybacked with rock-solid stability. ■ **Large 11" worm gears** on both axes, with factory-programmed Smart Drive™; periodic error less than 5 arc seconds. ■ **Automatic GO TO capability** to any object in the onboard 64,359-object database or to any input R.A. and Dec. ■ **High-Precision Pointing™** to within one arc-minute in the GO TO mode. ■ **DC servo drive systems** with integrated encoders and planetary gearboxes; encoder resolution: 0.13 arc secs. ■ **Six pushbutton-controlled drive-speed rates,** from photo-guide to fast-slew on both axes, simultaneously. ■ **Microprocessor controlled sidereal-rate tracking** in AZ or EQ modes with quartz accuracy. ■ **Home-Pulse Acquisition** permitting remote alignment and operation through a modem link to the telescope's RS-232 interface. ■ **Control panel connectors** for optional systems including CCD autoguiders and imagers, electric focuser, and the Meade **#1222 Field De-rotater** for long-exposure astrophotography in the AZ mode. ■ Available with **supergiant transportable field tripod** (2-person field set-up in less than 10 minutes); **permanent altazimuth pier** (permitting the entire instrument to be housed in a 2-meter dome); or **permanent equatorial pier** (in cases where piggybacked astrocameras do not permit field de-rotation).

Meade 16" LX200 Schmidt-Cassegrain, with Supergiant Transportable Field Tripod.

Write, call, or fax Meade Instruments for your free copy of the 100-page Meade General Catalog, with complete information on more than 40 Meade telescope models.

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The Meade 16" LX200 is in continuous production at the Meade Irvine, Calif. factory. **Delivery time:** 4 to 12 weeks. **Price:** $14,950, complete with supergiant field tripod, plus $385 packing and shipping in the 48 states; prices slightly higher with permanent altazimuth or equatorial pier.

MEADE EYEPIECES AND ACCESSORIES

Series 4000™ Super Plössls 52° field; multi-coated

Meade 4-element Super Plössls, updated and redesigned to utilize the latest in optical glass-types, are the finest general-purpose eyepieces available. For observing hairline lunar and planetary detail, splitting close doubles, or for deep-space; guaranteed to deliver more contrast and image sharpness than any other brand. Rubber eyeguards fold down for eyeglass wearers–a feature not available on competing brands. Multi-coated. All focal lengths through 32mm are parfocal.

Super Plössls (SP; 4-elements; 1.25"; 52°):
6.4, 9.7, 12.4, 15, 20, 26mm each: **$79.95** (3.45)
32mm (52°); **40mm** (44°) each: **99.95** (3.79)
56mm (52°; 2") **199.95** (5.48)

Series 4000™ Ultra Wide Angle 84° field; multi-coated

The ultimate eyepieces; extreme image sharpness over an amazing 84° field. A perfect optical match with Schmidt-Cassegrains and fast Newtonians.

Ultra Wide Angle (UWA; 8-elements; 1.25"; 84°)– **4.7mm: $169.95** (3.94); **6.7mm: 199.95** (3.94); **8.8mm** (1.25"/2"): **239.95** (5.87); **14mm** (1.25"/2"): **299.95** (6.28)

Series 4000™ f/6.3 Focal Reducer/ Field Flattener

Manufactured to exclusive Meade optical designs; threads on to any Meade or Celestron Schmidt-Cassegrain rear cell and converts f/10 scopes to f/6.3 (or f/6.3 SCT's to f/4), while significantly flattening the field. Use with SCT visual or photo accessories. Actual visual field is increased by 56%, for fine wide-field views of star fields and nebulae. In astrophotography, reduces exposure times by about 50%, while producing an actual field diameter of 1.5" at the film plane. A tremendous aid with CCD imagers in reducing image size for locating and centering images on CCD chips. 4-element optics; multi-coated; 41mm clear aperture.

$129.95 (3.60)

2x Telenegative Barlow (1.25")

#122: Doubles eyepiece power with sharp, high-resolution, high-contrast imaging on telescopes of all types. 27mm dia. (26mm clear aperture). Excellent corrections for chromatic and spherical aberrations at all photo-visual wavelengths. Multi-coated. 1.25"

$47.95 (3.45)

2x Short-Focus Barlow (1.25")

#126: Only 2.5" long, the #126 works well with any telescope accepting 1.25" eyepieces, even those with limited focus range. Maintains the high image quality of the #122, above. Insert the #126 into star diagonal for 2x or insert star diagonal into #126 for 3x. 26mm clear aperture. Multi-coated.

$47.95 (3.45)

2x-3x Variable Barlow (1.25")

#127: Precision internal sliding lens assembly permits continuously variable power settings between 2x and 3x. Engraved scale indicates power in use. Yields bright, sharp, high-contrast images on telescopes of all types. Multi-coated; 1.25".

$59.95 (3.45)

2" Diagonal Mirror

#929: Permits use of wide-field 2" oculars. Threads on to rear cell of Meade and Celestron SCT's. Includes multi-coated precision optical flat made at the Meade factory; with 1.25" eyepiece adapter. **#930:** Same as #929 but with 2" barrel to fit into focusers with 2" eyepiece-holders.

#929 or **#930,** each: **$99.95** (5.87)

45° Erecting Prisms

Fully coated roof prisms to invert the astronomical image in Schmidt-Cassegrains or refractors during terrestrial observations, while presenting a convenient 45° observing angle. Specify **#927** (.965"), **#928** (1.25"), or **#931** (fits .965" focuser, accepts 1.25" eyepieces).

$42.95 (3.45)

World's Most Advanced Illuminated Reticle Eyepiece

Series 4000 Plössl 9mm, with rubber eyecup and micrometric X-Y positioning of the reticle within the field. Greatly facilitates locking on the guide star. Sharp high-power imaging, excellent eye relief. Wireless red LED illuminator with adjustable brightness control. Multi-coated optics. **Internal batteries included.** Bullseye reticle. 1.25".

$149.95 (3.45)

Series 4000 Plössl 9mm—Same as above but with 6 ft. cord and plug for Meade LX3, LX5, LX6, LX100, LX200, and APO power panels, in place of wireless illuminator.

$129.95 (3.45)

Series 4000 Photo-Visual Color Filters (1.25")–Premium filters, made of purest crown optical glass, dyed in the mass. For increased contrast and resolution on the Moon and planets. Thread into the barrels of virtually all 1.25" eyepieces sold today. Fully coated.

#8 Lt. Yellow; #11 Yellow Green; #12 Yellow; #21 Orange; #23A Lt. Red; #25A Red; #38A Dark Blue; #47 Violet; #56 Lt. Green; #58 Green; #80A Blue; #82A Lt. Blue

each **$14.95** (2.29)

Set #1–4 filters: #12, #23A, #58, #80A **49.95** (2.98)
Set #2–4 filters: #11, #25A, #47, #82A **49.95** (2.98)
Set #3–4 filters: #8, #21, #38A, #56 **49.95** (2.98)

Series 4000 Moon Filter (#ND96): Reduces glare and irradiation during lunar observing. 13% uniform light transmission across the visual spectrum. Threads into 1.25" barrels. **$16.95** (2.29)

#905 Variable Polarizer (1.25")

For glare reduction in observing the Moon. Includes two Polarizer filters mounted in a machined cell and permits continuously variable light transmission from 5% to 25%, to compensate for varying lunar surface brightness according to the Moon's phase and the aperture of the telescope. Accepts 1.25" eyepieces. **$49.95** (4.27)

Modified Achromatic Eyepieces

Meade 3-element MA eyepieces yield sharp, well-corrected images on the Moon, planets, and deep-space at a reasonable price. Multi-coated; threaded for filters; 1.25" barrel diameter. Apparent field: 40°. **MA 9, 12, 25, 40mm.**

each: **$37.95** (3.45)

MA12mm Illuminated Reticle Eyepiece

Excellent 3-element optical system, long eye relief, fully coated, with double crossline reticle. Wireless red LED illuminator and variable brightness control. 1.25" **Batteries included.** **$99.95** (3.45)

As above but with 6 ft. cord and plug for Meade telescopes with power panels, in place of wireless illuminator. **$79.95** (3.45)

Camera Adapters

Professional-quality adapters for rigid coupling of telescope-to-camera. Use for either Eyepiece-Projection or Prime Focus. Precision-machined of aluminum and brass, threaded for filters. Use with T-mount, available separately.

.965": **$27.95**; 1.25": **$29.95** (2.98)

Variable Tele-Extender

For eyepiece-projection photography with any Meade or Celestron SCT. Threads on to eyepiece-holder. Sliding cell with lock permits wide range of projection magnifications with the same eyepiece. Use with T-mount for your camera.

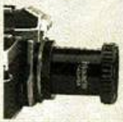
$39.95 (2.98)

Variable-Projection Camera Adapter (1.25")

Machined sliding cell allows variable projection power in eyepiece-projection photography; permits precise selection of correct photo power in lunar and planetary photography; threaded for filters. Use with T-mount for your camera.

$39.95 (2.98)

T-Adapters for SCT's



Rigidly couples camera to telescope for prime focus photography with any Meade or Celestron Schmidt-Cassegrain. Use with T-Mount for your 35mm camera.

$26.95 (2.98)

Series 4000™ 2x Apochromatic Barlow Lens

#140: The most advanced Barlow lens available for commercial telescopes, the Meade #140 includes 3-element, multi-coated, air-spaced optics. Doubles the power of any eyepiece with which it is used and yields images absolutely unmatched in resolution, contrast and color correction. The #140 optically complements any telescope — refractor, reflector, or Schmidt-Cassegrain. Accepts 1.25" eyepieces. Mechanical components are of machined aluminum and brass. Lens diameter is 28mm; clear aperture 26mm.

$79.95 (4.27)

Series 4000™ Super Wide Angle 67° field; multi-coated

For exquisite wide-angle images at low-to-medium powers, with pinpoint edge-of-field resolution. Ideal for star fields, galaxies, and other deep-space phenomena. SWA 13.8mm, 18mm, and 24.5mm are superb complements to the #140 Barlow, above.

Super Wide Angle (SWA; 6-elements; 1.25"; 67°)–**13.8mm: $139.95** (3.94); **18mm: 149.95** (3.94); **24.5mm: 179.95** (4.68); **32mm** (2"): **239.95** (5.87); **40mm** (2"): **299.95** (6.28)

Series 3000™ Plössls 50° field; multi-coated

The very latest in eyepieces from Meade optical designers, new Meade Series 3000 Plössls yield the finest image corrections obtainable from the classical 4-element Plössl design. Available in a wide range of focal lengths from 5mm through 25mm. All five eyepieces are parfocal, so that, at most, only slight refocusing of the image is necessary from eyepiece to eyepiece. Unlike competing moderately-priced Plössls, Meade Series 3000's are **multi-coated** for maximum light transmission and image contrast. Chrome-plated brass barrels are threaded for standard filters. Manufactured exclusively for Meade Instruments by one of Japan's leading lensmakers, Series 3000 Plössls produce fine, high-resolution results on reflectors, refractors, and Schmidt-Cassegrains of any focal ratio.

Series 3000 Plössls (4-elements; 1.25"; 50°)
5, 6.7, 9.5, 16, 25mm each: **$49.95** (3.45)

#911B
#910B
#908B
#911N
#910N
#908N

Series 4000 Nebular Filters—Premium multi-layer interference filters, the finest obtainable. Use broadband ("B") filters to block most forms of light pollution; use narrowband ("N") filters in heavily light-polluted areas or for extremely high-contrast observing of faint nebulae.

#908B–Threads into 1.25" eyepieces, 26mm dia. **79.95** (3.45)
#910B–Threads into 2" eyepieces, 44mm dia. **119.95** (3.85)
#911B–Threads on to rear cell of Schmidt-Cassegrain telescopes. 36mm dia. **99.95** (3.94)
#908N–Threads into 1.25" eyepieces, 26mm dia. **89.95** (3.45)
#910N–Threads into 2" eyepieces, 44mm dia. **129.95** (3.85)
#911N–Threads on to rear cell of Schmidt-Cassegrain telescopes. 36mm dia. **119.95** (3.94)

Series 3000™ Plössl 40mm 44°

An excellent complement to the Series 3000 Plössls above, this all-new Plössl 40mm produces spectacular low-power, wide-field results with any telescope. Includes classical 4-element Plössl optics, **multi-coated.** Barrel dia. 1.25"; threaded for filters. Apparent field: 44°.

$79.95 (3.79)

HOW TO ORDER

Prices shown are suggested U.S.A. mail-order retail prices and do not include any applicable sales taxes. Suggested shipping and handling charges to the 48 states by U.P.S. or U.S. Mail shown in ( ) next to each price. **The following national mail-order dealers carry all Meade accessories in-stock for immediate shipment:**

ASTRONOMICS, Norman, OK.
Orders: 800-422-7876; Info.: 405-364-0858.

CALIFORNIA TELESCOPE CO., Burbank, CA.
Orders & Information: 818-505-8424.

FOCUS CAMERA, Brooklyn, NY.
Orders: 800-221-0828; Info.: 718-436-6262.

LUMICON, Livermore, CA.
Orders: 800-767-9576; Info.: 510-447-9570.

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Orders: 800-569-4323; Info.: 717-842-1500.

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Orders: 800-245-7963; Info.: 603-742-4888.

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Orders & Info.: 800-621-2248; IL: 312-332-2000.

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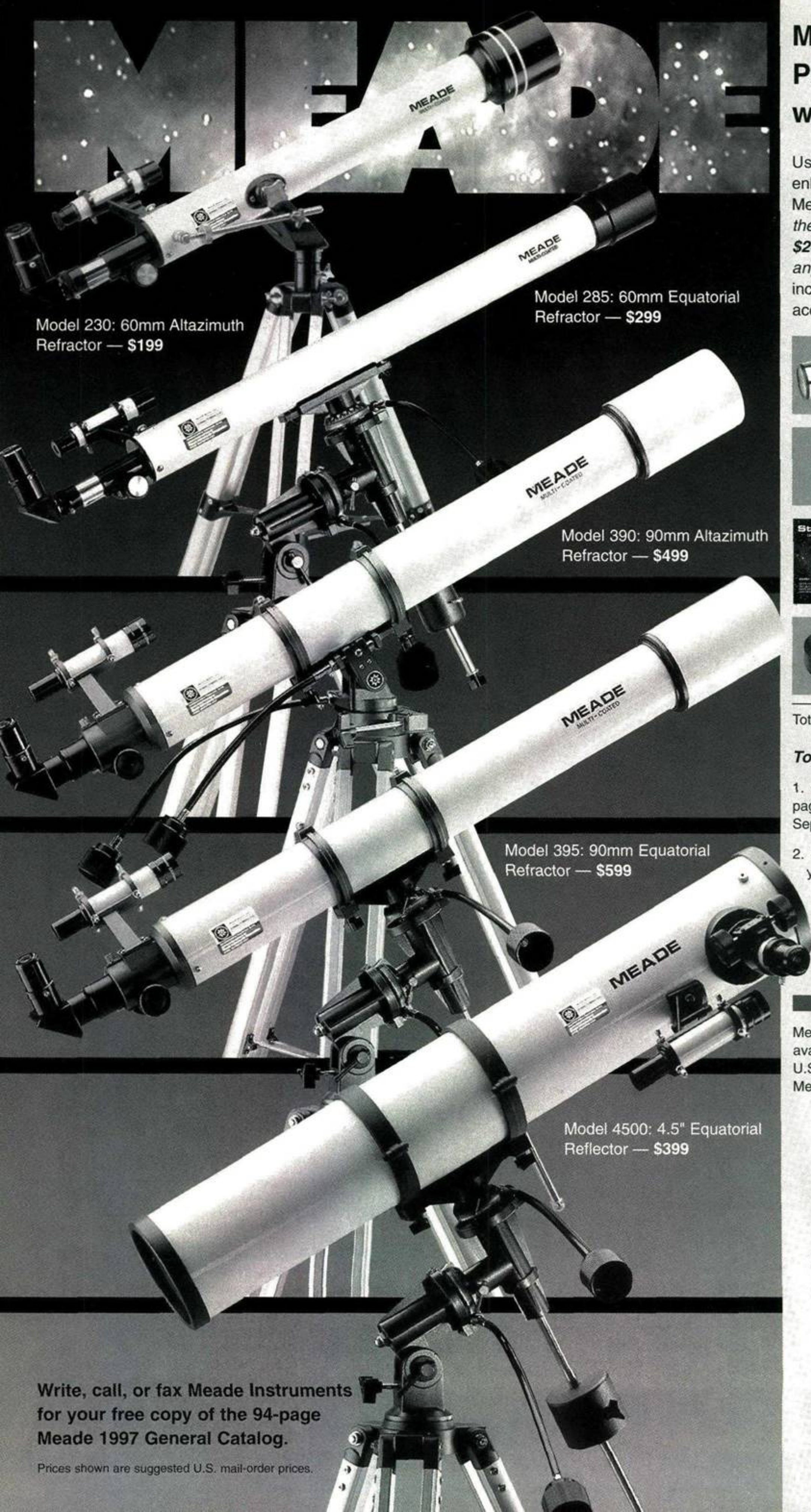

Model 230: 60mm Altazimuth Refractor — **$199**

Model 285: 60mm Equatorial Refractor — **$299**

Model 390: 90mm Altazimuth Refractor — **$499**

Model 395: 90mm Equatorial Refractor — **$599**

Model 4500: 4.5" Equatorial Reflector — **$399**

Meade® $175 Observer's Package: only *$24.95* with telescope purchase!

Use the **Meade Observer's Package** to enhance the versatility and performance of your Meade telescope. *Priced separately at **$178.80**, the Observer's Package is available at only **$24.95** for a limited time, when purchased with any Meade telescope on this page,* and includes the following important astronomical accessories:

Meade #126 2x Barlow Lens (1.25"). A high-resolution, multi-coated achromatic Barlow; doubles all eyepiece powers.	**$47.95**

Meade Modified Achromatic (MA) 12mm Eyepiece. Ideal mid-range magnification for the Moon and planets; multi-coated.	**37.95**

StarNavigator

Meade Star Navigator™ Sky Software. Windows-based software that displays over 10,000 galaxies, nebulae, star clusters, and planets on your PC	**79.95**

Meade Moon Filter. Threads into all Meade 1.25" eyepieces; reduces glare, increases contrast of lunar features.	**12.95**

Total Package Price if purchased separately: **$178.80**

To obtain your Meade Observer's Package:

1. Purchase one of the five Meade telescopes on this page from a Meade dealer of your choosing, between September 1 and December 31, 1997.
2. Send a copy of your dealer's invoice, along with your check for $24.95, or include your VISA or MasterCard number, to Meade Instruments Corp., 16542 Millikan Ave., Irvine, CA 92606.

Requests for the above offer must be received by January 31, 1998. Offer valid only in the U.S.A. and Canada. Please allow 30 days for delivery.

Meade astronomical telescopes and accessories are available from over 500 authorized dealers in the U.S.A. and Canada, including the following authorized Meade Advanced Products Mail-Order Dealers:

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Orders & Information: 818-505-8424.

FOCUS CAMERA, Brooklyn, NY.
Orders: 800-221-0828; Info.: 718-436-6262.

LUMICON, Livermore, CA.
Orders: 800-767-9576; Info.: 510-447-9570.

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Orders & Information: 800-483-6287.

POCONO MOUNTAIN OPTICS, Moscow, PA.
Orders: 800-569-4323; Info.: 717-842-1500.

RIVERS CAMERA, Dover, NH.
Orders: 800-245-7963; Info.: 603-742-4888.

SHUTAN CAMERA & VIDEO, Chicago, IL.
Orders & Info.: 800-621-2248; IL: 312-332-2000.

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MEADE 102ED/APO EMC
MEADE 203/SC EMC
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(top) Model 102ACHR/500:
4" f/9 Achromatic
Refractor — **$995**

(left) Model 102APO/500:
4" f/9 *ED* Apochromatic
Refractor — **$1695**

LXD 500 Series

Imagine yourself at the controls of a Meade LXD 500 - series telescope, ready for an extremely wide range of advanced photo-visual applications. Each instrument includes the all-new Meade LXD 500 equatorial mounting, with dual-axis bronze worm gears, engraved setting circles, and micrometric controls in RA and Dec. as well as for azimuth and polar elevation alignment. Choose from among three models the one that's right for your budget and observing requirements.

For complete details send for your free copy of Meade Bulletin 500.

Prices are for **complete** astronomical telescopes, as shown, including optical tube assembly, LXD 500 equatorial mounting, rigid aluminum tripod, and a full complement of accessories:

Model 102ACHR/500: **4" f/9 Achromatic Refractor**	**$ 995**
Model 102APO/500: **4" f/9 *ED* Apochromatic Refractor**	**1695**
Model 203SC/500: **8" f/10 Schmidt-Cassegrain**	**1295**
#1701 Single-Axis RA Drive System	**145**
#1702 Dual-Axis Drive System, with 4-speed (2x, 8x, 16x, 32x) hand control	**195**
#1708 Computer Drive System, with LX200-type hand control, 4°/sec. slewing, Smart Drive™, and 64,359-object library.	**795**
#812 Polar Alignment Finder	**49**

Packing & shipping: 4" models—$55; 8" model—$65.

Model 203SC/500:
8" f/10 Schmidt-
Cassegrain — **$1295**

Shown with optional #1708 Computer Drive System

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Meade Instruments Corporation

World's Leading Manufacturer of Astronomical Telescopes for the Serious Amateur

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TALKING BACK
FROM OUR READERS

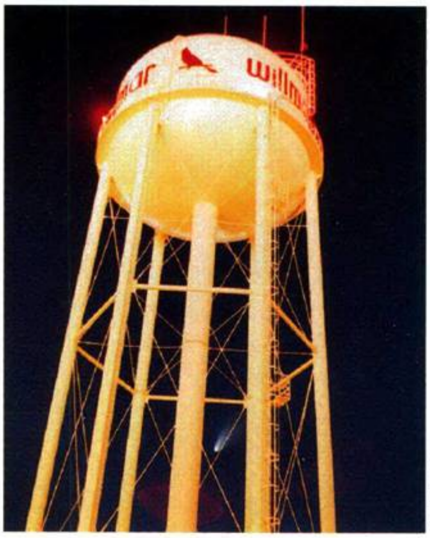
The Big UFO Response

I noticed a photo on page 34 of the September issue ("A Field Guide to UFOs") depicting unidentified "flying saucers" supposedly seen over Sicily in 1954. Is this perhaps a camera lens internal reflection pattern caused by sunlight in that daytime scene?

I had a somewhat similar nighttime result when photographing Comet Hale-Bopp at the site of one of our city water towers on April 13, 1997 — two red "flying saucers" of an ethereal type caused by internal lens reflections from the top, bright red tower lights. (See photo at right.) There is also an angled orientation difference of one red "blob" relative to the other as was true in the Sicilian photo.

I also see that the three people in the 1954 photo are not apparently looking directly at the "flying saucers," but rather at a scenic landscape view. Is this photo perhaps a hoax, being passed off as a sighting of UFOs? — *Randall Wehler, Willmar, Minnesota*

Robert Naeye responds: The flying saucers photographed by Giuseppe Grasso over Sicily in 1954 remain unidentified. What you present could certainly be considered a plausible explanation, but the age and quality of the photograph make arriving at definite solutions difficult.


Randall Wehler

I would like to explain the origin of the picture of the UFO at Chalk Mountain, Colorado, on page 33 of your September issue. It was taken by my father, Robert Rinker. He claimed to have seen nothing in the sky at the time the picture was taken. He only claimed that the camera he was using prevented any double exposures, and therefore the image must be real.

In spite of this, the image is almost certainly the result of an accidental double exposure. The object is probably an incandescent lamp inside a cylindrical sheet metal reflector which had a rolled edge (creating the dark line along the bottom of the object). My father used this sort of lamp in his workshop and the exposure of the lamp likely happened in the process of loading the camera. (The photo in question was the first exposure on the roll.)

The composition of the double image, which accounts for much of its compelling nature, is entirely fortuitous, although it has been helped over the years by skillful cropping by those who have republished it. I hope this sets the record straight. — *Susan Rinker Frensley, Richardson, Texas*

I have just finished reading "A Field Guide to UFOs" by Philip Klass. It was such an obvious case of one-sided journalism that I actually felt some disdain toward the magazine for publishing it. I say one-sided because it didn't take an honest look at the opposite side of the coin; Mr. Klass simply set up a straw man and then knocked it down — and your magazine let him. I say disdain because this was so apparent that I felt my intelligence was being insulted. Honest journalism might see you publish a response by UFO researchers of a different persuasion. — *Dean De Lucia, São Paulo, Brazil*

(cont. on p. 19)

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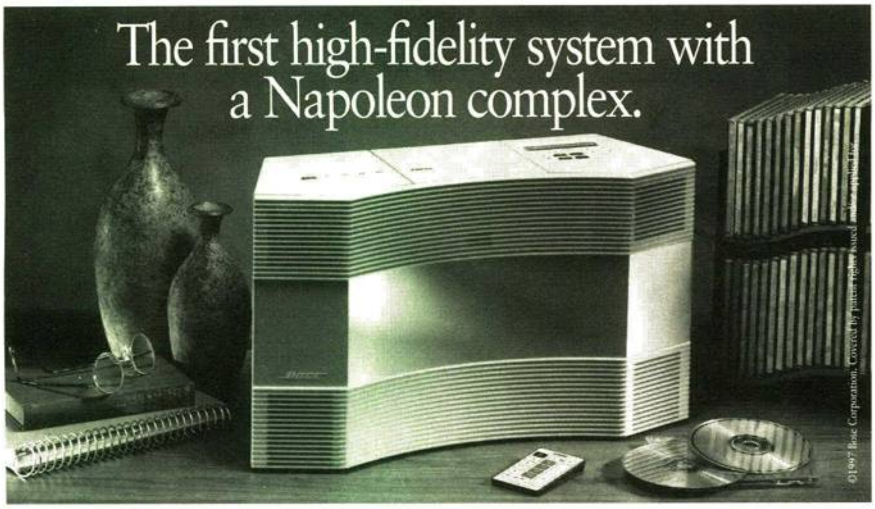
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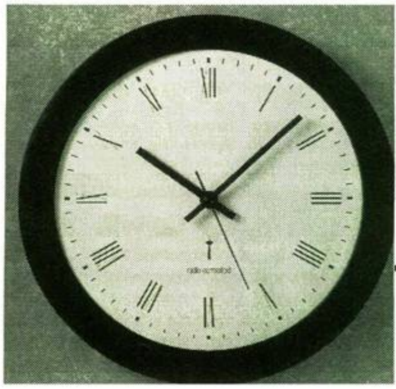

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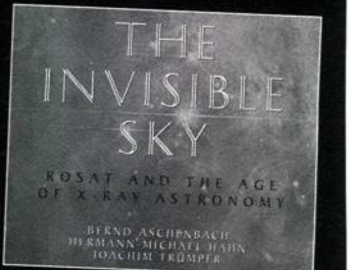

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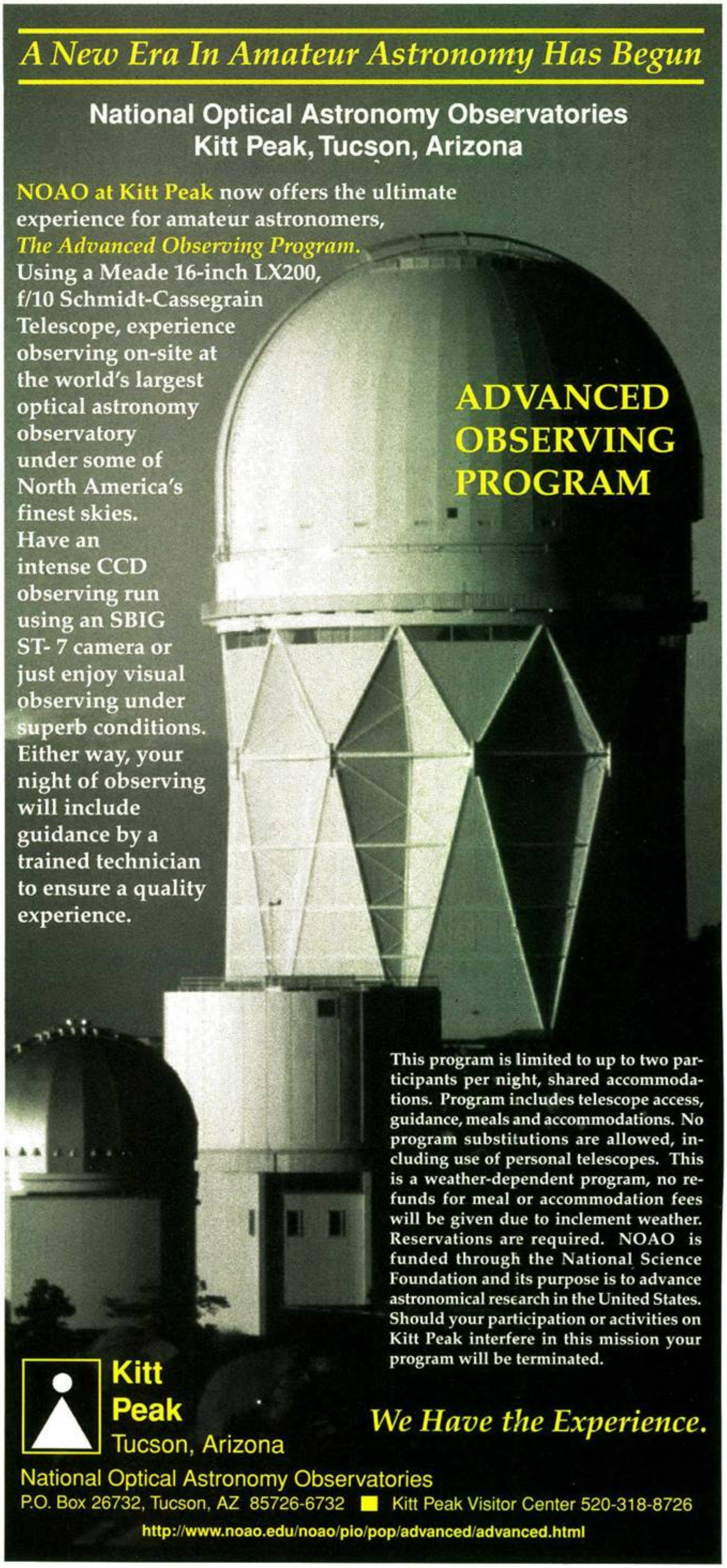

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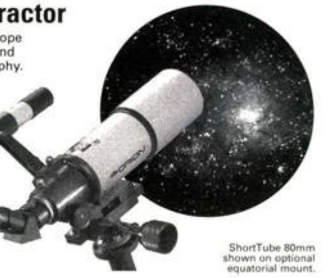
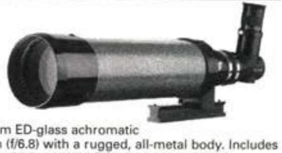


ShortTube 80mm shown on optional equatorial mount.

Tele Vue

Ranger 70mm Refractor



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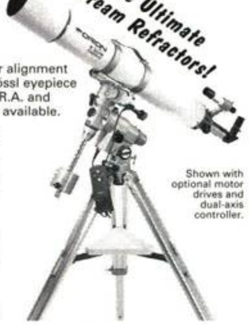

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MISSION UPDATE

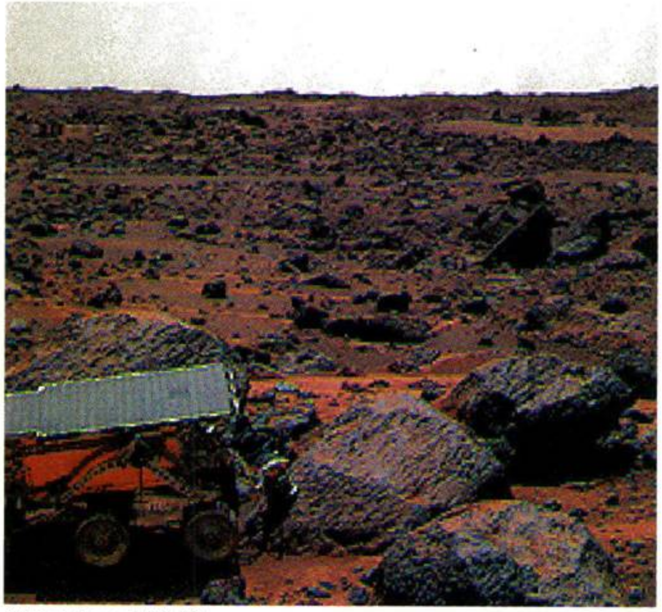
Pathfinder Keeps Rolling Along

Rover's battery dies, but mission goes on

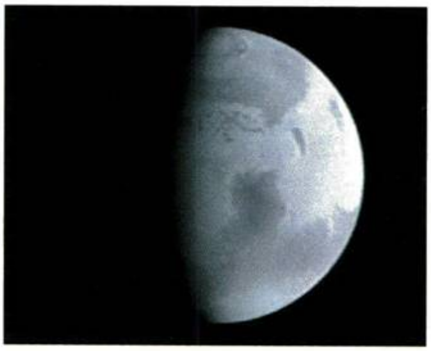
▶ Shortly before Mars Global Surveyor successfully entered orbit around Mars on September 11, the Mars Pathfinder mission suffered a minor setback. As engineers knew would happen sooner or later, the rover's battery died, which means Sojourner can operate only off its solar panel during daylight. Overall, however, the lander and rover continue to perform magnificently. "Every single measurement we had hoped to make we have managed to make," says project scientist Matt Golombek of NASA's Jet Propulsion Laboratory.

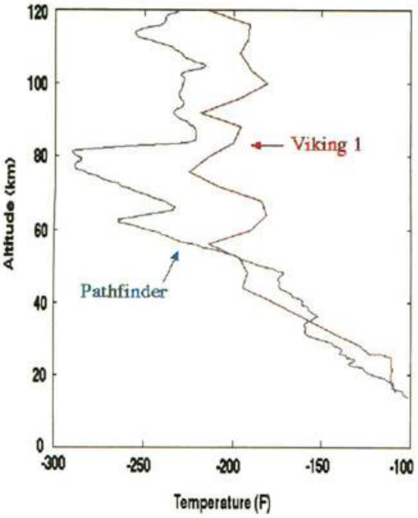
By mid-September, Sojourner's alpha proton x-ray spectrometer had chemically analyzed eight rocks. These rocks appear to fall into two broad categories. One class, represented by Barnacle Bill and Shark, is rich in silica. The other class, which includes Yogi and Wedge, is rich in sulfur. "That was our hope when we selected this site, to get a smorgasbord of rock types. Two different kinds is better than one, four is better than two," says Golombek.

Data taken during Pathfinder's descent through the atmosphere show that Mars was colder at high altitude (above 30 miles, or 50 kilometers) than it was in 1976 when the Viking landers arrived. At 50 miles (80 km) up, Pathfinder found a temperature of –297° F (90° C above absolute zero). At that frigid temperature, carbon dioxide can condense to form noctilucent-like clouds. At an altitude of 6 miles (10 km), Pathfinder recorded a sudden cooling of 36° F (20° C). This could lead to the formation of morning clouds containing water ice crystals similar to high-altitude cirrus clouds on Earth. The lander's imager photographed early morning clouds, the first clouds ever seen from Mars's surface.



All images this page: NASA/JPL





The Sojourner rover sniffs Moe with its alpha proton x-ray spectrometer (above). The rover has found two different kinds of rock on Mars, one rich in sulfur and the other rich in silica. The martian atmosphere at high altitudes appeared significantly colder than it did when Viking 1 landed back in 1976 (left). These temperatures could explain the formation of the clouds seen by Pathfinder. The next spacecraft set to explore Mars is Global Surveyor, which arrived on September 11. One of its early images (above, left) shows the gibbous disk of the Red Planet.

Despite the water clouds, the atmosphere is remarkably dry. "If all of the water in the atmosphere condensed onto the surface, the thickness of the global ocean would be only one-tenth the thickness of a human hair," says atmospheric scientist Mark Lemmon of the University of Arizona. "We expect a zero percent probability of rain," jokes Tim Schofield of JPL.

Scientists are also learning about Mars's powdery soil. "The information we learn about the surface of Mars and how the rover interacts with it, particularly when we start driving away from the lander, is very important. We're learning things that are very applicable to future rover missions," says Golombek.

BRIGHT FIREWORKS

A Pair of Colliding Supernovae

Space Telescope reveals a surprising double bubble

▶ Astronomer William Blair of Johns Hopkins University thought he had captured a rare astrophysical animal: an

(see "Supernovae," p. 26)

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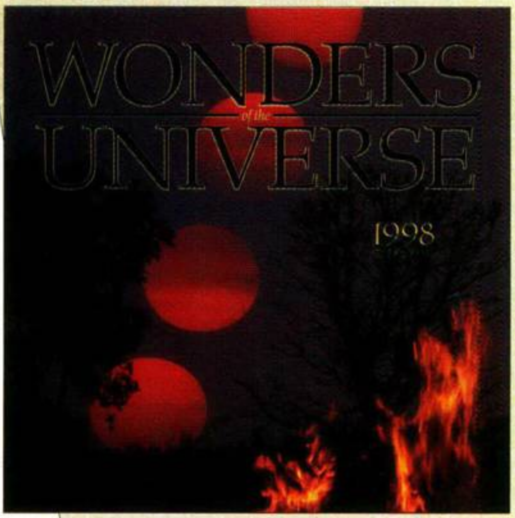

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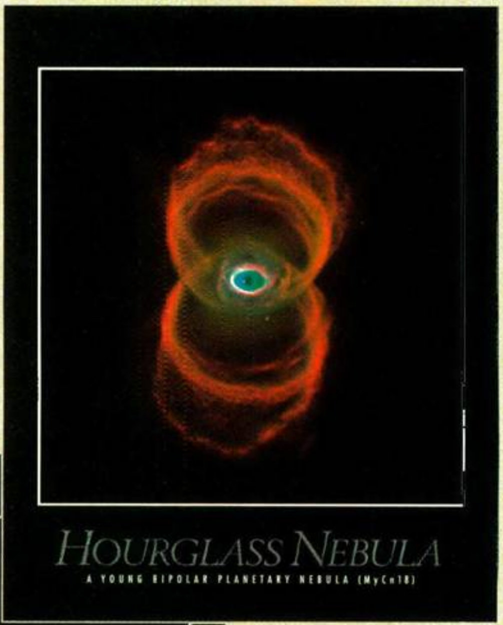

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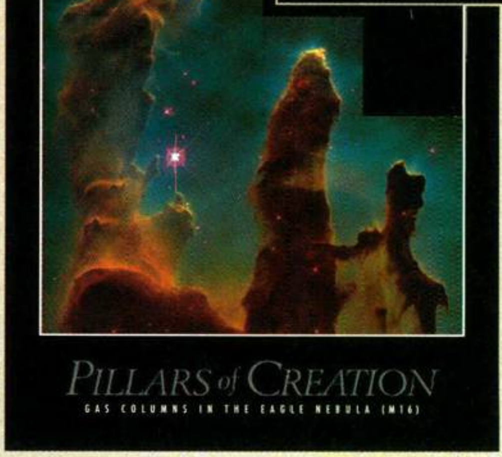

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ASTROPHYSICAL FRONTIERS

HST Spies Bare Black Hole

Peering deep into the active galaxy NGC 6251 in Virgo, the Hubble Space Telescope has imaged a warped, dusty disk caught in a blazing torrent of ultraviolet light from a suspected black hole. "This is a completely new phenomenon that has never been seen before," says Philippe Crane of the European Southern Observatory in Garching, Germany. "It blew my mind away."

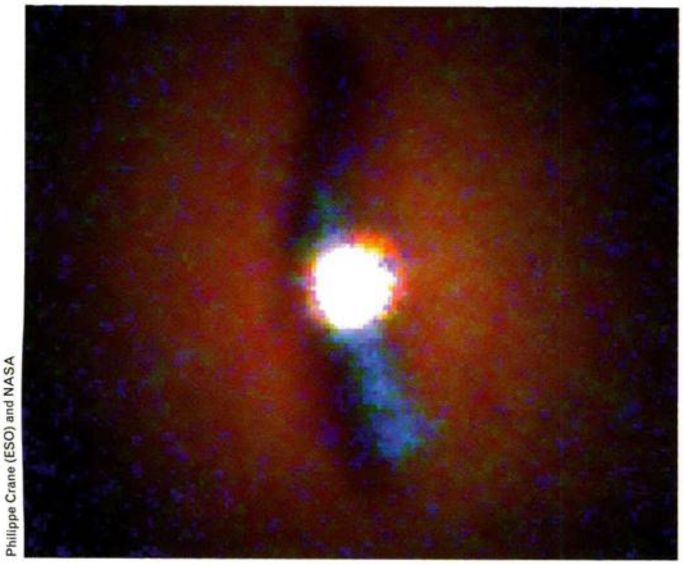
Other black holes observed by Hubble are mostly hidden from view because they are embedded inside a dusty torus. NGC 6251 offers the first clear example of an "exposed" black hole illuminating the surrounding disk.

Crane and his co-investigator Joel Vernet, also of ESO, used the Faint Object Camera to take a high resolution ultraviolet image of the galaxy's core. The two found ultraviolet light reflecting off one side of the disk, suggesting that the disk is warped like the brim of a hat.

The warp could be caused by gravitational perturbations that keep the disk from being perfectly flat. Another possibility is that the black hole's rotation axis precesses relative to the galaxy's axis.

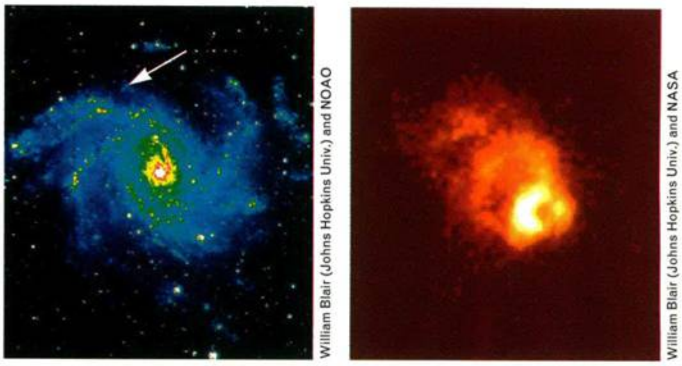
Strong circumstantial evidence for a black hole comes from the 3-million-light-year-long jet of radiation and particles emanating from the elliptical galaxy's core. The team used Hubble's sensitivity to ultraviolet light to look for structure in

(see "Black Hole," p. 28)



Philippe Crane (ESO) and NASA

A dusty disk warped like the brim of a hat lies in the core of galaxy NGC 6251 in Virgo. This Hubble composite combines a visible light image showing the dark disk with an ultraviolet image (colored blue) revealing a bright feature on one side of the disk. The bright white spot is light from near the black hole that illuminates the disk.



William Blair (Johns Hopkins Univ.) and NOAO

William Blair (Johns Hopkins Univ.) and NASA

A ground-based image of the galaxy NGC 6946 in Cepheus (left) shows what was first thought to be a single supernova remnant. But a Hubble closeup (right) reveals debris from two or more colliding supernovae. Most of the light comes from a crescent-shaped region where debris from the youngest remnant plows into an older, bigger shell.

(Supernovae)

extremely young supernova remnant in a distant galaxy. But when he and his colleagues observed the remnant with the Hubble Space Telescope, they realized they had something far rarer — a pair of supernova remnants crashing into each other.

The object first gained the team's interest when they saw it glowing brightly in both visible light and in x rays. Located near a spiral arm of the galaxy NGC 6946 in Cepheus, it had all the earmarks of a young supernova remnant — the gaseous remains of a massive star that exploded after exhausting its nuclear fuel. Finding such a remnant, this one apparently only a couple hundred years old, would help astronomers studying the massive stars that create supernovae.

The researchers were puzzled, however, when they examined optical spectra of the remnant. The expanding cloud of debris seemed to be moving far too slowly, and the gases making up the cloud were not as enriched in heavy elements as they expected. It looked for all the world like an old supernova remnant slowly diffusing into the interstellar medium.

The sharp views provided by Hubble finally solved the mystery. The bright point of light seen from the ground resolved into at least two remnants colliding with one another. A close look at the image shows a fairly young remnant, perhaps 2,000 years old and about 25 light-years in diameter, crashing into one or two older remnants. The collision heats the gas to a high temperature, causing the visible and x-ray emission.

Although thousands of supernovae have been seen in distant galaxies, Blair says "This is the first time we've identified one of these interactions right when the shells are in the process of slamming into each other."

CAMBRIAN EXPLOSION

Tipsy-Turvy Earth

Did a shift in Earth's axis spur evolution?

At the start of the Cambrian period, 544 million years ago, an "evolutionary Big Bang" swept the globe,

(see "Earth," p. 28)

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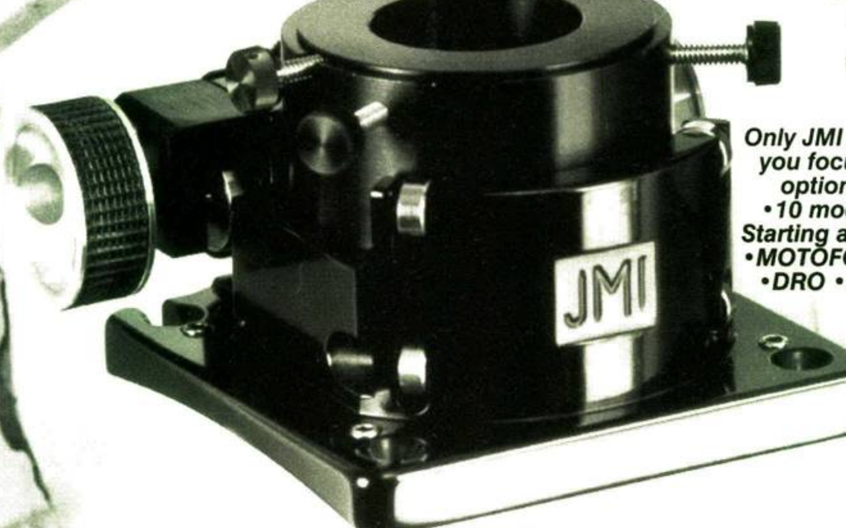

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One of the most monumental achievements in the history of JMI – Creation of a speed reducer that adds only half an ounce! (Some focus knobs weight three times more.)

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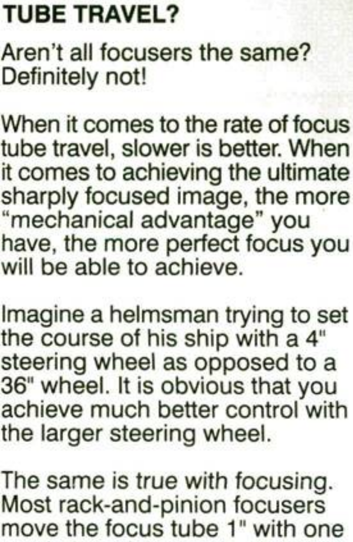
Aren't all focusers the same? Definitely not!

When it comes to the rate of focus tube travel, slower is better. When it comes to achieving the ultimate sharply focused image, the more "mechanical advantage" you have, the more perfect focus you will be able to achieve.

Imagine a helmsman trying to set the course of his ship with a 4" steering wheel as opposed to a 36" wheel. It is obvious that you achieve much better control with the larger steering wheel.

The same is true with focusing. Most rack-and-pinion focusers move the focus tube 1" with one revolution of the knob. All of JMI NGF-focusers have, in the past, moved the focusing tube .58" per revolution.



Pat # 5,303,090-10-24-1992

JMI's motto: Strive constantly to surpass yourself not the competition.

It is time to once again surpass ourselves.

Introducing the 1998 line of focusers from JMI. The NGF-Dx2 delivers .39" travel per revolution. *The NGF-Dx1 has two speeds. The fast knob delivers .39" per revolution and the micro fine knob, delivers an incredible .075" per revolution that translates to more than 13-times finer action than most rack-and-pinion focusers.

Secondly...

We now also have an enclosed frame which is stronger than before. We went back the drawing board and back to one of our original patents -a totally enclosed one-piece Crayford focuser with captivated bearings.

All JMI focusers are still free of image shift. They are still gearless and pressure driven, and they still provide the ultimate focus.

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"To put it bluntly, if there's a better line of commercial focusers made for imaging, I don't know about it." Dennis di Cicco - 3/94 Sky & Telescope

- Summer 1991, JMI develops the first zero-image shift focuser
- Summer 1992, JMI develops the first NGF-S (for SCTs)
- October 1992, JMI patents first one-piece Crayford focuser.
- Spring 1993, JMI offers the first low-cost NGF focusers
- March 1994, JMI markets the first one-piece focuser with 10 models to choose from

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NGF-DX2 2" with 1.25" adapter Lifts up to 6 lb.	$199 ($5)
NGF-DX3 2" with 1.25" adapter Lifts up to 5 lb.	$159 ($5)
NGF-DX4 2" Lifts up to 2.5 lb.	$119 ($5)

NGF-mini2	1.25"	$129 ($5)
NGF-mini3	1.25"	$ 99 ($5)
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DRO (digital focusing)		$229 ($5)
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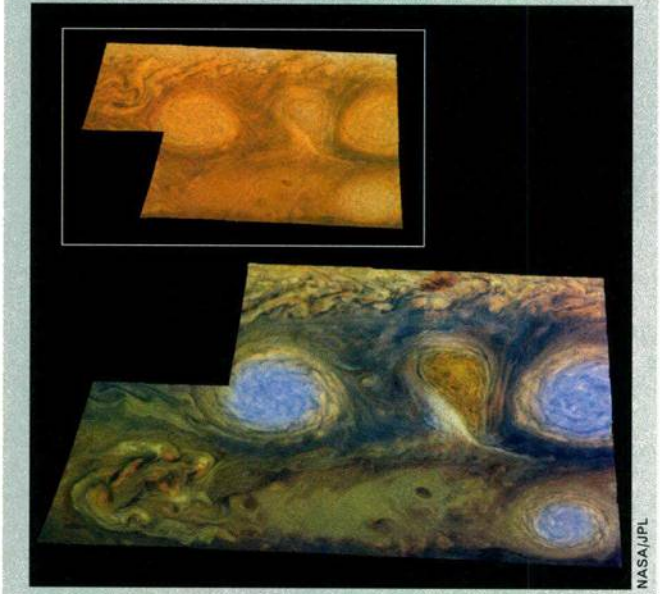
(Black Hole)

the hot gas at the base of the jet.

Crane was surprised to see a finger-like object extending from the nucleus and running parallel to a 1,000-light-year-wide dust disk. He concluded that the ultraviolet light must be reflecting off dust in a disk or the back wall of a ring. Such a ring could have formed when radiation plowed out a cavity around the black hole.

GALILEO



NASA/JPL

JUPITER'S WHITE OVALS: The balloon-shaped vortex lying between the two white ovals is a cyclonic system located in Jupiter's southern hemisphere. The larger white ovals are two of the three long-lived white ovals that formed south of the Great Red Spot in the 1930s. Like the Red Spot, they rotate counterclockwise; the balloon-shaped vortex rotates clockwise.

The white ovals, which drift in longitude relative to one another, were restricting the cyclonic structure when the Galileo spacecraft took this image on February 19, 1997. (The oval at left stretches 9,000 kilometers, or 5,600 miles, from east to west.) To the south, the smaller oval was drifting eastward at about 0.4° per day relative to the larger ovals. The interaction among the systems produced the high, thick cumulus-like clouds along the southern edge of the cyclone.

The top mosaic combines violet and near-infrared images to create a view similar to what the human eye would see. Trace chemicals in Jupiter's atmosphere cause the different colors.

The lower mosaic combines three near-infrared images to show variations in cloud height and thickness. The white clouds are high and thick and the light-blue clouds are high and thin. The reddish clouds lie deep in the atmosphere, while the dark purple color likely represents a high haze lying above a clear, deep atmosphere. The clouds and haze above the white ovals appear to extend into the jovian stratosphere.

(Earth)

filling the oceans with new animal life. Now a team of scientists at Caltech has come up with a radical new explanation for this watershed in life's history — that a rather sudden lurch in the very foundations of the planet and the wild climate fluctuations that followed spurred the evolution of new species and body plans.

The researchers proposed in the July 25 issue of *Science* that Earth's crust and mantle shifted 90° from its rotation axis in response to a reshuffling of its internal mass. Such "true polar wander" events have occurred before in the planet's history, but never as large as the one now proposed. To correct the imbalance, the crust and mantle slid sideways over a period of 15 million years, redistributing mass toward the equator. At the same time, Earth's spin axis kept the same orientation with respect to the plane of the solar system. Some planetary scientists think a similar event carried the massive Tharsis volcanic province to the equator of Mars.

Using a record of past shifts in Earth's magnetic field preserved in ancient rock formations, the scientists reconstructed the epic journeys of the continents that ensued. Australia rotated counterclockwise some 90°, and North America relocated from the Southern Hemisphere to the equator. The motions happened so quickly that they cannot be explained by the much slower drift of Earth's tectonic plates, the scientists argue.

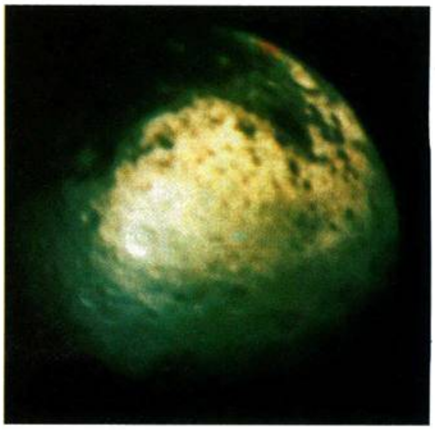
— **Daniel Pendick**

SATURN'S ODD MOON

Iapetus's Split Personality

▶ Planetary scientists may finally have a complete explanation for perhaps the strangest moon in the solar system. One hemisphere of Iapetus, Saturn's outermost large satellite, appears as dark as coal while the other reflects light like new-fallen snow. Although scientists had a general idea as to what causes this dichotomy, Douglas Hamilton of the University of Maryland proposes a more detailed scenario that answers many nagging questions. He presented his findings at the July meeting of the Division for Planetary Sciences in Cambridge, Massachusetts.

As Earth has done to our moon, Saturn has tidally



Half of Saturn's moon Iapetus appears white while the other half is jet-black. Scientists think this comes about as dust from its sister moon Phoebe gathers on Iapetus's leading hemisphere. But the dust's exact location can only be explained by realizing that the moon was not tidally locked to Saturn for a billion years. NASA/JPL

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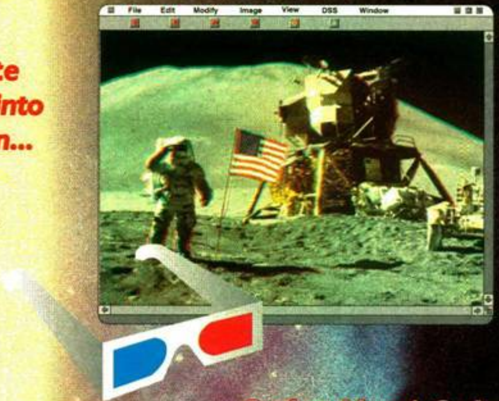

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locked Iapetus so that it always keeps one side facing the planet. The jet-black hemisphere faces forward as the moon revolves around Saturn and the bright white half lies on the trailing side. Scientists have long suspected that Phoebe, a small, even more distant satellite of Saturn, sheds dust that spirals inward, coating the leading hemisphere.

A few problems exist with this simple model, however. For one, the dark material doesn't match precisely what this model predicts. Also, dark-floored craters exist in the bright hemisphere, and the north polar region appears brighter than parts of the trailing hemisphere.

Hamilton argues that most of these problems disappear when you realize that Iapetus took a billion years to become tidally locked. He suggests that while Iapetus spun more rapidly, it accumulated dust across most of its surface. (Though more dust landed near the equator, leaving the poles bright white.) After Iapetus became locked, the trailing side was shielded from additional dust and ice slowly buried the dark material. Large impacts on the trailing side then dredged up some of the ancient dust, creating the dark-floored craters.

OUTER SOLAR SYSTEM

More Kuiper Belt Objects

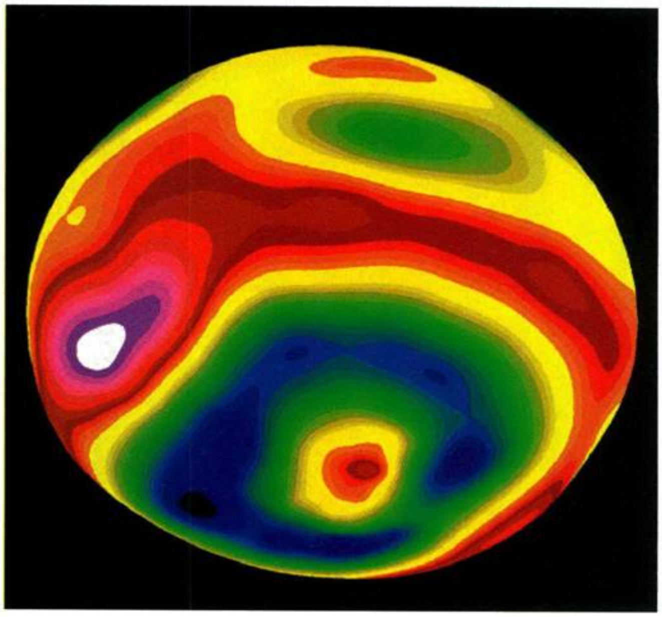
The number stands at 56, and it's still climbing

▶ About the only thing keeping pace with the stock market in recent years has been the rising number of objects orbiting the sun beyond Neptune. A team of planetary scientists that includes Jane Luu of Harvard University and David Jewitt, Jun Chen, and Chadwick Trujillo of the University of Hawaii has recently discovered nine new trans-Neptunian objects, upping the known grand total to 56 (including Pluto).

These objects populate a region of space known as the Kuiper Belt, which starts just beyond the orbit of Neptune and stretches to perhaps 150 astronomical units (150 times the average distance between the sun and Earth). The Kuiper Belt consists of an estimated 70,000 icy planetoids at least 60 miles in diameter and billions of smaller worlds.

The researchers discovered the nine objects with the University of Hawaii's 2.2-meter reflector on Mauna Kea. The team used a new CCD detector that has an 8,192 by 8,192 pixel array, which makes it the world's largest astronomical CCD. The team's previous CCD had an array of only 2,048 by 2,048 pixels. "We cover more area per night with our new CCD, which makes it much easier to find Kuiper Belt objects," says Jewitt.

One of the most recently discovered objects, 1996 TO_{66}, has a diameter of almost 500 miles, about one-third that of Pluto's. "There might be Kuiper Belt objects larger than Pluto," says Jewitt. "We have not seen any yet, presumably because such objects are rare and orbit the sun at large distances."



The giant 460-kilometer-wide crater and its 13-km-high central peak appear near the south pole of Vesta in this color-coded elevation map (above) made from Hubble observations. The peak appears prominent in this 3-D computer model (left).

Ben Zellner (Georgia Southern Univ.), Peter Thomas (Cornell Univ.), and NASA

ANCIENT COLLISION

Hubble Finds Big Crater on Vesta

▶ Astronomers observing the large, bright asteroid Vesta with the Hubble Space Telescope have discovered a crater 85 percent the diameter of the asteroid. The crater forms a vital link in a chain of events likely responsible for creating a family of small asteroids as well as some meteorites that have reached Earth.

The collision that formed the crater gouged out a hole 13 kilometers (8 miles) deep and 460 km (285 miles) across, nearly equal to the asteroid's overall diameter of 530 km (330 miles). The hole represents 1 percent of Vesta's volume. The crater also features a giant central peak similar to those seen in many lunar craters. Towering 13 km above the crater's floor, the peak formed when molten rock sloshed back to the center after the impact.

The researchers, led by Peter Thomas of Cornell University, took 78 images with Hubble in May 1996, when Vesta was at its brightest and closest to Earth for the past decade. The team reported their findings in the September 5 issue of *Science*.

The huge crater lies near Vesta's south pole. That may not be a coincidence — the scientists think that the removal of so much material would have shifted the rotation axis so the crater would end up near one pole.

Even the crater itself isn't all that shocking. Astronomers have known for years about a distinctive class of small asteroids having colors similar to Vesta's that they

(see "Vesta," p. 34)

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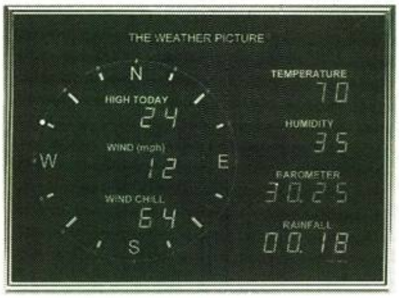

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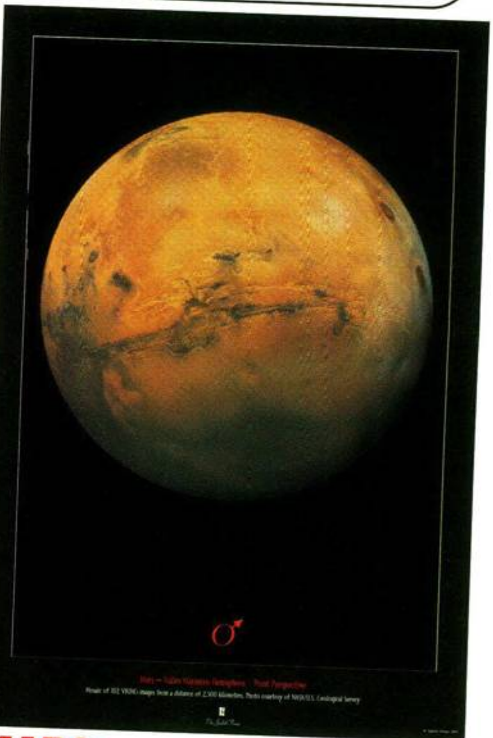

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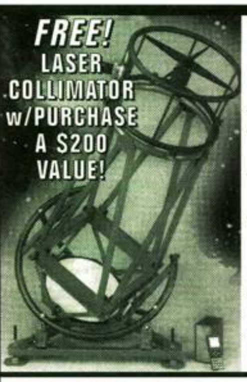

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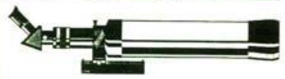

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(Vesta)
viewed as "chips off the old block." And about 6 percent of all meteorites — the howardite, eucrite, and diogenite classes of basaltic achondrites — appear nearly identical to Vesta but unlike any other large asteroid. "In hindsight we should have expected finding such a large crater," says Thomas. "But it's still a surprise when it's staring you in the face."

UP CLOSE WITH HUBBLE

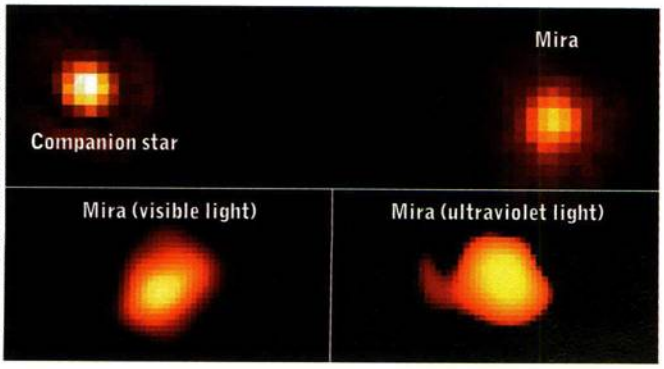
Seeing Double with Mira

▶ Using the remarkable resolving power of the Hubble Space Telescope, a team of astronomers led by Margarita Karovska of the Harvard-Smithsonian Center for Astrophysics has viewed both the optical and ultraviolet light from the two components of a binary system in which one object is accreting matter from the other. The system is a familiar one to variable star observers: the pulsating red giant star Mira, 400 light-years away in Cetus. Mira expands and contracts in a cycle that averages about 331 days; at its largest size, it would fill two-thirds of the space between the sun and Jupiter's orbit.

Mira also has a much smaller and hotter companion star. The two stars lie about 70 astronomical units apart (a little less than the diameter of Pluto's orbit), meaning they appear separated by only 0.6 arcsecond (the width of a dime seen four miles away). In ground-based telescope images, atmospheric effects smear the two stars together.

As Mira expands and contracts, it sheds tremendous amounts of gas and dust via a powerful stellar wind. The companion's gravity attracts some of this material, which forms an accretion disk around the companion before spiraling into the star.

Astronomers are hoping that Hubble images such as these will help them better understand how the accretion process works. In an image taken in ultraviolet light, a hook-shaped appendage is clearly seen sticking out from Mira. "It could be strands of Mira's stellar wind interacting with the companion," says team member Edward Guinan of Villanova University.



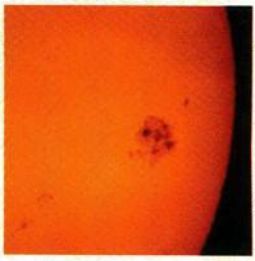
Margarita Karovska (Center for Astrophysics) and NASA

In the main Hubble image (top), the red giant star Mira appears to the right of its smaller companion. In visible light, Mira has a football shape. In ultraviolet light, it has a hook-shaped extension that might represent material being drawn toward the companion. The companion is not visible in either of the smaller images.

Toothpaste in Space

Last year it was vinegar, this year it is fluoride. Astronomers keep adding to the list of molecules found in interstellar space. Using the European Space Agency's Infrared Space Observatory satellite, a team of American and German astronomers discovered trace amounts of hydrogen fluoride (a molecule consisting of one hydrogen atom and one fluorine atom) in a giant cloud of interstellar gas near the galactic center. This is the first time a molecule containing fluorine has ever been discovered in interstellar space.

Watery Sunspots



James Kevin Ty

Water vapor apparently lurks in dark, cool sunspots.

Astronomers have suspected that sunspots contain water vapor, but they haven't been able to prove it because they haven't heated steam to the 3,200-kelvin temperature of the dark, central regions of sunspots. But Oleg Polyansky and Jonathan Tennyson of University College London and colleagues reported in the July 18, 1997, *Science* that computer models of the infrared spectrum of a watery sunspot match actual infrared spectra of sunspots, virtually proving that sunspots do indeed contain water vapor. Water cannot exist elsewhere on the sun because the intense heat breaks it apart.

Massive Neutrinos?

While not all physicists are convinced, three new experiments provide further evidence that the ghostly subatomic particles known as neutrinos have mass. Two of the experiments, one in Minnesota and one in Japan, observe naturally produced neutrinos. The other, at the Los Alamos National Laboratory in New Mexico, creates neutrinos in a particle accelerator. All three experiments showed one type of neutrino changing into another, an event that can only occur if neutrinos have mass. If neutrinos have mass, they could make up a significant portion of the universe's mass. It would also explain why the sun produces fewer neutrinos than theory predicts.

New Hubble Instrument

NASA has selected a group at the University of Colorado and Ball Aerospace & Technologies Corporation in Boulder, Colorado, to build a new spectrograph for the Hubble Space Telescope. The Cosmic Origins Spectrograph will shed light on conditions in the early universe by studying ultraviolet light from distant stars, galaxies, and quasars. The $25-million instrument is scheduled to replace COSTAR during the 2002 servicing mission.

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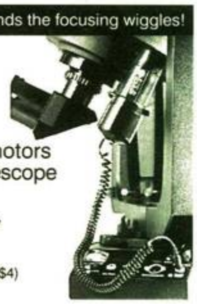

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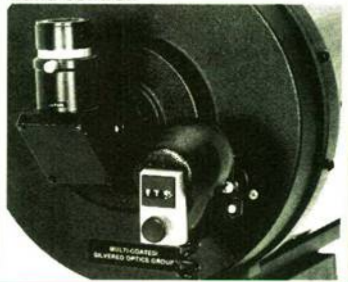

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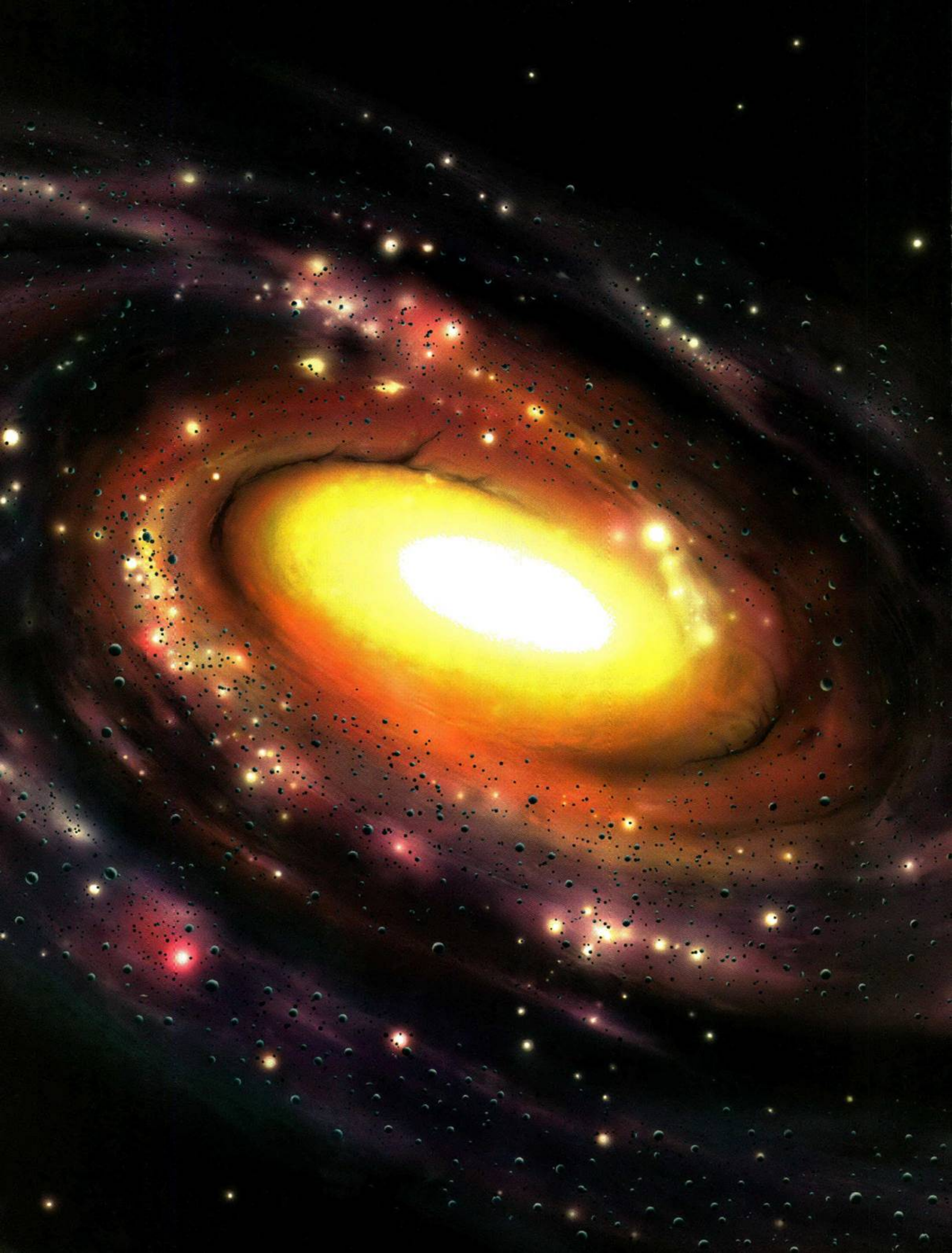


Astronomy: Elisabeth Rowan

If Harvard astronomer Rudy Schild is correct, trillions upon trillions of rogue planets (represented by the small black and white dots) roam freely in each and every galaxy.

On the Trail of Rogue Planets

Floating freely in space, unattached to stars, rogue planets might populate most galaxies by the quadrillions.

by Peter Catalano

Even science has its folklore and myths — among them "rogue" planets. For years a few astronomers theorized that these objects — about the size of Earth or Uranus — wandered freely on the peripheries of galaxies and interstellar space unfettered by the gravitational leash of shepherding stars. Undetectable and unobservable, rogue planets existed in a nebulous theoretical limbo.

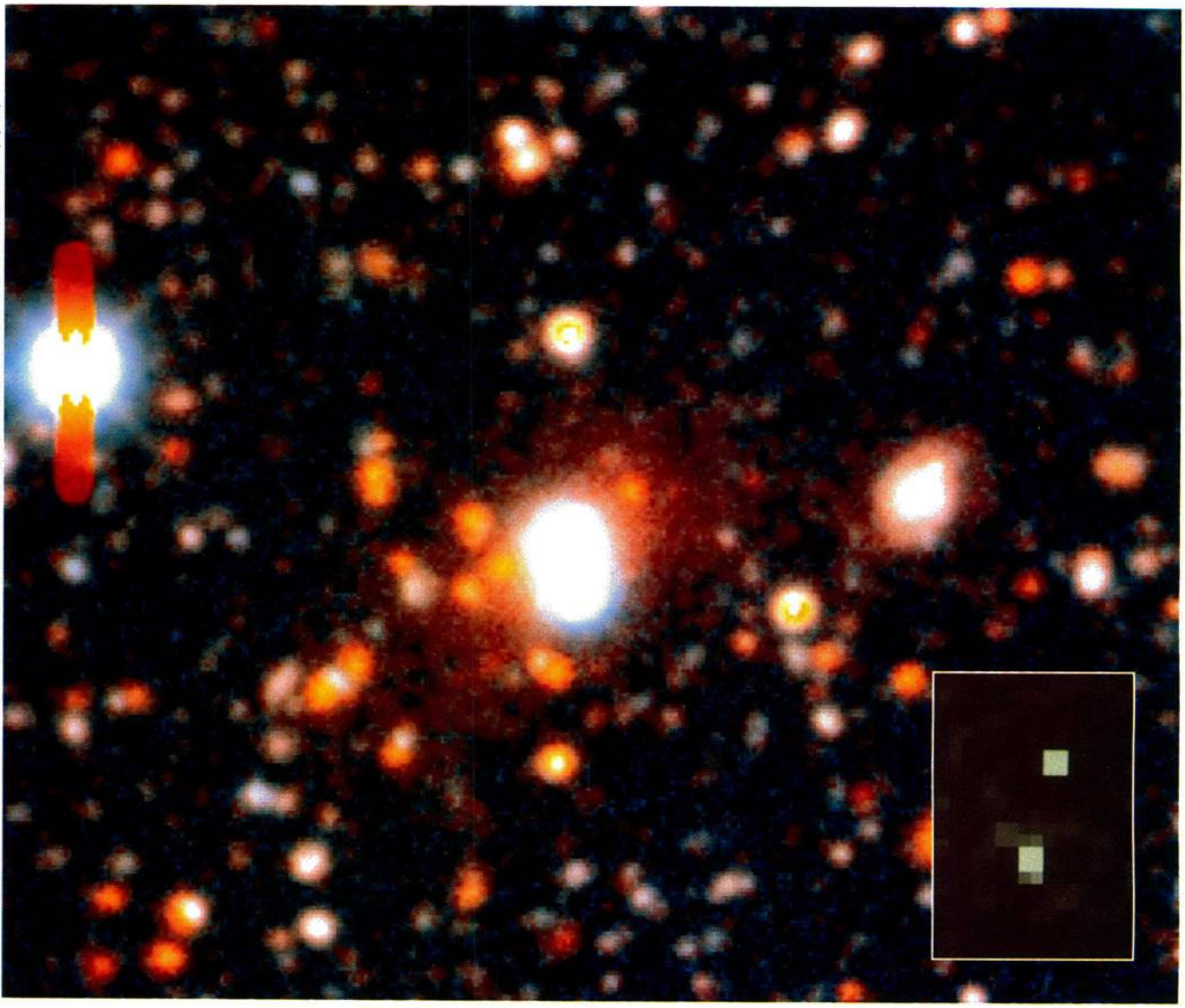
Little by little they slipped unconsciously into the lexicon of astro-talk. "The phrase came into use about 30 years ago," explains physicist Freeman Dyson from his office at the Institute for Advanced Studies in Princeton, New Jersey. "I'm not sure who first started talking about them. The idea was just something in the air. As far as I know, there is no evidence that so-called rogue planets exist."

Until now.

In June 1996, Rudy Schild of the Harvard-Smithsonian Center for Astrophysics in Cambridge, Massachusetts, published observational data accumulated over 10 years that seemed to show that rogue planets could not only be demonstrably real, but could be ubiquitous, even essential species on the taxonomic tree of astronomical objects. Schild's gone even further: He thinks rogue planets are virtually a cosmic Rosetta stone, the key to understanding some of the most vexing enigmas in astrophysics.

Schild reported in the June 10, 1996 *Astrophysical Journal* that he and his collaborator, statistician David Thomson of Lucent Technologies, found the gravitational signature of at least 50 Earth- to Uranus-mass objects maundering on the fringes of an elliptical galaxy one to two billion light-years away. This galaxy is catalogued simply as G1.

By any measure, this could be a big discovery — a big discovery few astronomers are buying. Critics concede, however, that the observations themselves are unimpeachable. In fact, multiple observatories all detect the same phenomena Schild reports seeing on his own 1.2-meter telescope at the Mt. Hopkins Observatory in Arizona. When you get right down to it, this rogue planet dispute is not over facts, but interpretation.



Philip Fischer, Gary Bernstein (University of Michigan) and J. Anthony Tyson (Lucent Technologies); Inset: Rudy Schild (Harvard-Smithsonian Center for Astrophysics)

One quasar, two images: The foreground galaxy G1, seen as a faint blip in the inset photo, acts as a gravitational lens. It splits light from quasar 0957+561 into two images, seen in both the main photo and the inset. The light from one beam arrives 415 days ahead of *the other*.

Seeing Double

Frozen and lifeless, hundreds of degrees below zero, too far from starlight to be seen, rogue planets can only be identified indirectly by their tell-tale gravitational tracks. They can be found using a technique called gravitational lensing, which is derived from Einstein's general theory of relativity. It's a phenomenon that occurs when gravitational fields generated by whole galaxies or individual objects (such as stars and planets) bend and distort background light from more distant objects in the same line of sight.

This "lensing" effect magnifies light from the background object by focusing some of its divergent light rays toward Earth. The object causing the lensing itself often isn't visible; but you can observe the effects of its gravitational field on background light. From there, its mass can be inferred. Rogue planets are found by gravitational microlensing; the "micro" in microlensing simply refers to the lensing effect of a low-mass object, such as a planet, where the brightening of the background light is small and short-lived.

In the case Schild is studying, the light source is a quasar, the black-hole-driven energetic core of a distant galaxy. Matter falling into the gravitational sink created by this black hole forms an accretion disk. As the matter spirals toward its doom, it emits intense streams of radiation.

The quasar is identified by its catalogue number, Q0957+561 (Q0957 for short). If you look at an image of Q0957, you see two practically identical star-like images, simply referred to as A and B. The intervening galaxy G1, fortuitously situated almost halfway between Earth and the quasar, splits Q0957's light into two beams, creating a mirage.

One of the beams passes through G1 much more than the other. Evidence of rogue planets comes from fluctuations in the intensity and duration of Q0957's light as it cuts through G1. The gravitational fields of objects in G1, presumably rogue planets, cause these luminosity changes.

Schild interprets *short-lived modulations in* quasar Q0957's brightness — low-amplitude changes in luminosity of two to five percent that last several weeks — as indications of microlensing events. "Here's the key for interpreting these objects," says Schild. "For stars, the cycle of waxing and waning lasts for decades; for rogue planets, brightness and dimming cycles run their course in a matter of weeks. These short-lived 'flickers' imply that the passing object in the lensing galaxy is about a millionth the mass of the sun because we know the square root of the mass is proportional to the duration of the brightness cycle. When you solve the equation, the mass of the microlensing object is something like a medium-sized planet in our own solar system."

Troubling Time Delays

Having two beams emanating from the same source conveniently provides an opportunity to compare the behavior of the nearly "pure" beam shining almost directly from Q0957 with the behavior of the beam that's "lensed" in the galaxy G1. With this lensing configuration, one beam serves as an observational control against the other, which is important because the quasar itself pulses. Intrinsic quasar pulsing causes jumps in brightness that could be mistaken for microlensing effects.

To separate the two effects, Schild has developed the following strategy: If both quasar images simultaneously wax or wane, then the quasar itself must be acting up. But if there are sudden, small amplitude changes in luminosity only occurring in the beam shining through the lensing galaxy, then, Schild concludes, the gravitational field of an object in G1 must be crossing near the telescope's line of sight.

All this sounds straightforward, but it isn't. Closer inspection of microlensing in G1 shows how daunting, if not outrageous, the entire rogue planet proposition is. After all, the delicate beams of quasar Q0957 are very, very faint by the time they reach Earth. The channel that slices into G1 is bouncing among the gravitational fields of innumerable stars and, according to Schild, among gravitational fields of drifting rogue planets in G1.

Even the relatively simple idea of comparing the quasar's twin images in order to detect microlensing in G1 isn't quite as mechanical as might be imagined. In addition to the maze of gravitational webs, light from the quasar takes longer to pass through the denser medium of a lensing galaxy, creating a time delay that retards its arrival on Earth by 415 days or so.

Last year, two other observatories, one affiliated with Princeton and the other in the Canary Islands, converged on the same time delay. This came as no small victory for Schild and Thomson, who first calculated the correct delay back in 1987. It's critical to get the time lag right. "Knowing the time delay allows us to retrieve images stored 415 days ago and compare them with gravitationally lensed images just now reaching us," explains Schild. "That way we can match simultaneous quasar events and deduce which entity is causing flickers on our telescope — the quasar itself or something else, like rogue planets."

Like most astronomers, Edwin Turner of Princeton University is skeptical of Schild's rogue planet interpretation. Still, he freely admits that his own observatory detects these same rapid fluctuations in Q0957's lensed image. "There are small little departures" between light curves coming from the quasar in channel A (the "pure" beam) and channel B (the beam cutting through the galaxy G1), says Turner. "We've looked carefully at our data and we can't find any way of explaining away these small discrepancies as due to some problem with the instrumentation. That is to say, they look to us to be real."

Colossal Swarms?

As elements of Schild's rogue planet scenario have begun falling into place, Schild has been raising the ante. Using microlensing data, Schild has some empirical basis for sketching a new profile of galaxies that is a lot more crowded, its texture far more complex, than we ever thought.

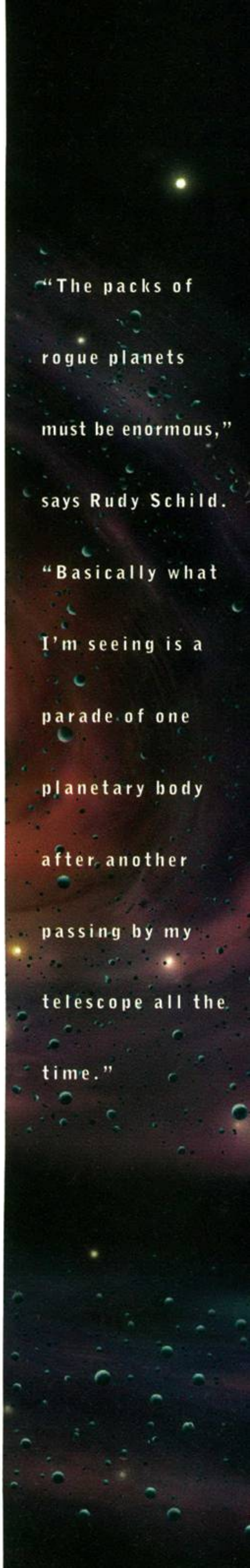
Even with the powerful Hubble Space Telescope, the sky we see at night is only a small protruding tip of an otherwise vast hidden cosmos. Though we can now observe billions of galaxies, each thousands of light-years across, each populated with billions of stars, all that turns out to be only an insignificant fraction of what lies out there. Just 10 percent.

Rogue planets, claims Schild, comprise the other 90 percent of the universe which, until now, remained hidden from detection, cold and dark. Schild may have uncovered the first hint of the domains that lie on the other side of the darkness.

According to Schild's estimate, so great in numbers are rogue planets that there are a million for every star. The total magnitude of the missing mass, he calculates, exceeds the rest of the visible sky by a ten-to-one margin; this ratio generates just enough gravity to explain the unexpectedly high rotation rates of the outer regions of spiral galaxies such as the Milky Way.

"The packs of rogue planets must be enormous," says Schild. He draws such inferences from the spacing between each of the 50 rogues he's already detected. By astronomical standards, it's a traffic jam — each rogue being about 0.1 light-year apart. "Basically what I'm seeing is a parade of one planetary body after another passing by the observational line of sight of my telescope all the time. That's why I have such confidence that I've detected massive patches of rogue planets."

Such density works out to *quadrillions* of rogue planets hiding in G1, an elliptical galaxy which doesn't seem in any way unique. Projecting Schild's findings in G1 onto the rest of the observable universe implies the existence of at least 10^{24} rogue planets. Schild is either on to something very significant that has monumental implications, or he's the butt of a sardonic cosmic joke.



"The packs of rogue planets must be enormous," says Rudy Schild. "Basically what I'm seeing is a parade of one planetary body after another passing by my telescope all the time."

The Christmas Tree Quasar

Is the universe toying with Rudy Schild and David Thomson — like Descartes's "Evil Demon"— contriving to deceive them into believing that rogue planets are real? Maybe it's not the devil, but most astronomers do think other forces are playing hob with Schild's rogue planet data.

"I would be cautious about the interpretation," says Turner. "It's important to remember" that the quasar's luminosity fluctuations are "much smaller and weaker than the events we hang the time delay on, so I don't feel bullish about the discrepancies people would like to interpret as microlensing."

Turner says the objection most astronomers have to Schild's interpretation is that the model he is using is too simplistic: It assumes that he is seeing individual microlensing events caused by single objects when in reality, G1 is full of stars and other assorted objects. "You've got a lot of things along the line of sight," says Turner. "If you're looking through a whole cloud of microlenses, then the behavior is much more complicated, and you can get all sorts of variations in brightnesses on all sorts of different time-scales, and it tells you nothing simple. There's no easy, simple, direct relationship between the masses of the microlenses and the timescales of the variation."

Turner also points out that standard microlensing light curves have a characteristic symmetric shape. "What's seen in Q0957, the little blips in the light curve, looks nothing like the standard microlensing light curves. That tells you that the model he's using to deduce the mass of these things is wrong."

Turner's fellow Princetonian Bohdan Paczynski and Andrew Gould of Ohio State are staking out some imaginative scenarios to account for the low amplitude "flickers" showing up in Harvard and Princeton's telescopes. Their hypothesis: These events aren't caused by passing parades of rogue planets. Instead, pulsing hot spots in the quasar Q0957 — a veritable array of blinking lights that resemble a Christmas tree — are the source.

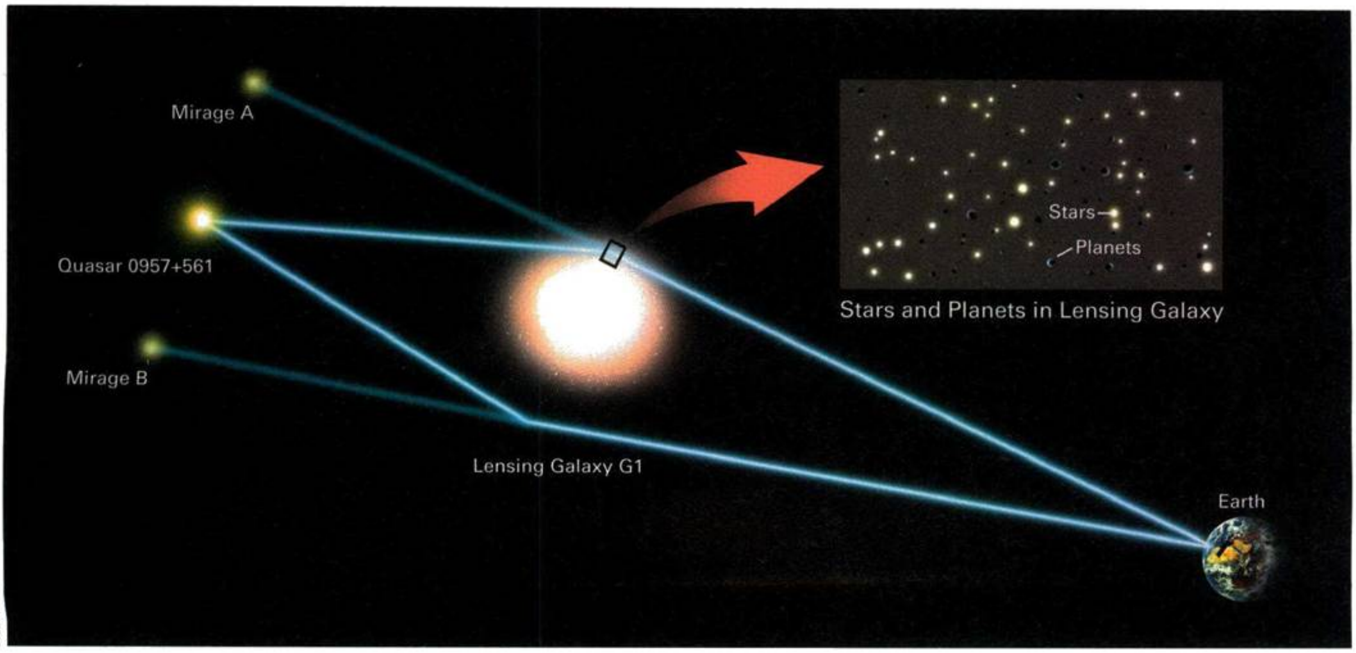
Last July, Gould and Jordi Miralda-Escudé of the University of Pennsylvania fired the first volley in a paper entitled "Signatures of Accretion Disks in Quasar Microlensing." Jets flowing at nearly the speed of light from the quasar's surrounding accretion disk, they conjecture, become microlensed when their luminous signatures cross the overlapping web of gravitational fields in G1. In this scenario, stars (not planets) lens the accretion jets, making them brighter or darker. This effect mimics the signatures rogue planets might display. That, Gould and Miralda-Escudé suggest, is how Schild is being deceived.

Schild responds that he and David Thomson anticipated this hypothesis even before it was published. "A while ago Dave and I did a little test. If the quasar's hot spots are causing the low amplitude brightness fluctuations we observe, then they should be predominantly periodic. That's because the hot spots are inside the quasar's accretion disk, which is rotating. As the disk spins, you should see the hot spots return on a regular basis corresponding to the disk's rotational speed. But it doesn't; we can't find such periodicities."

Turner jumps to Gould's defense, however, noting that quasar hot spots are not necessarily going to be periodic: "Sunspots are on a spinning object, but they're not periodic; they come and go all the time."

Schild remains unshaken. "Analysis of our large database using very advanced statistical methods encourages Dave Thomson and me to believe we have addressed every one of the tough technical issues in a reasonable and credible fashion. Of course, time will tell; but all this reminds me of the wrangling over the time delay.

The gravity of intervening galaxy G1 splits the light from quasar Q0957+561 into two beams, creating the illusion of a double quasar. Light from the one beam cuts through G1 more than the other. Several telescopes have observed "flickers" in the beam cutting through G1, flickers that Rudy Schild interprets as being due to microlensing by rogue planets.



Astronomy: Elisabeth Rowan

It took 10 years, but in that case we got it right despite years of dismissive skepticism."

Jon Chase

Rudy Schild has sparked a firestorm of controversy with his contention that rogue planets comprise a large fraction of the universe's dark matter.

Fighting with MACHOS

If massive populations of rogue planets are as ubiquitous as Schild claims, why don't we see them in our own Milky Way Galaxy?

Two projects, an American one called MACHO and a French one called EROS, were designed to detect gravitational lensing effects in our home galaxy. While the MACHO group has possibly detected two rogue planets in the Milky Way Galaxy, MACHO team-member David Bennett of the University of Notre Dame says they could also be planets in distant orbits around low-mass stars. Bennett adds, "Both the EROS and MACHO collaborations have set upper limits on the contribution of rogue planets to the mass of the Milky Way Galaxy. They must be considerably less than 10 percent of the total mass. If we assume that our galaxy has the same composition as the galaxy that lenses the quasar, then our results indicate that Rudy's interpretation must be wrong."

Schild thinks there's every reason to believe there are lots of rogue planets in the Milky Way. MACHO and EROS haven't found them because he believes these programs aren't optimized to detect planet-mass objects. "Their focus is finding low-mass stars and brown dwarfs, which are hundreds or thousands of times the mass of rogue planets. The lensing set-up with Q0957 and G1 is the best configuration we have for finding low-mass, planetary objects," he says.

Schild expects that his rogue planets would be gaseous bodies formed around a core of hard rock or ice, such as Uranus. At the atomic level, the elements found in both gas, ice, and rock consist of ordinary protons and neutrons — "baryonic" matter. Astrophysicists contend, however, that the Big Bang couldn't possibly have created enough baryonic matter to account for that much dark matter. That's why they have been theorizing and searching for non-baryonic matter called WIMPs (Weakly Interacting Massive Particles) and other exotica such as massive neutrinos to account for the dark matter.

Of course, the weightiest question Schild confronts is simply: Where do all these rogue planets come from? Schild himself has proposed that rogue planets are hatched in enormous numbers, a million for every star, in the accretion disk cocoon out of which stars themselves are formed. Even sympathetic astronomers are skeptical of this proposition.

However, Andrew Gould concedes, "Our interpretation of the microlensing hypothesis is somewhat clouded mainly because of our lack of theoretical understanding."

Addressing the same point, Fred Franklin, Schild's colleague at the Center for Astrophysics, speaks the language of a neutral empiricist who puts the onus on the theoreticians. "You certainly go first with the observations, and then try to fit them into a comprehensive theoretical pattern. So I'm all in favor of new and exciting observations."

Franklin points out some good reasons why Schild's findings might appeal to some astronomers. Principally, there's an elegant simplicity at play. Indeed, "The more common the constituents of cold, dark matter turn out to be, the happier people are." Cold, dark matter constructed of familiar elements, whose nuclear components are baryonic, are more reassuring and familiar to astronomers. No exotica are required.

For his own part, Schild is content to leave it to others to settle the enigmas posed by his research and is moving on to other projects. Says Schild, "I fully expect microlensing and rogue planets to grow into a central controversy in astronomy that both the observational folks and theoreticians will grapple with for some time. My hunch is that with microlensing, nature has handed us a marvelous opportunity to crack some of her deepest mysteries." After a pause, he adds, "It may not immediately bring us closer to discovering alien life, or even raise the probabilities of life elsewhere in the universe. But rogue planets, I predict, will eventually explain a lot about the cosmic terrain and point the way to answering some big questions. After the discovery of rogue planets, the sky seems a bit less spooky. At least it does to me." A

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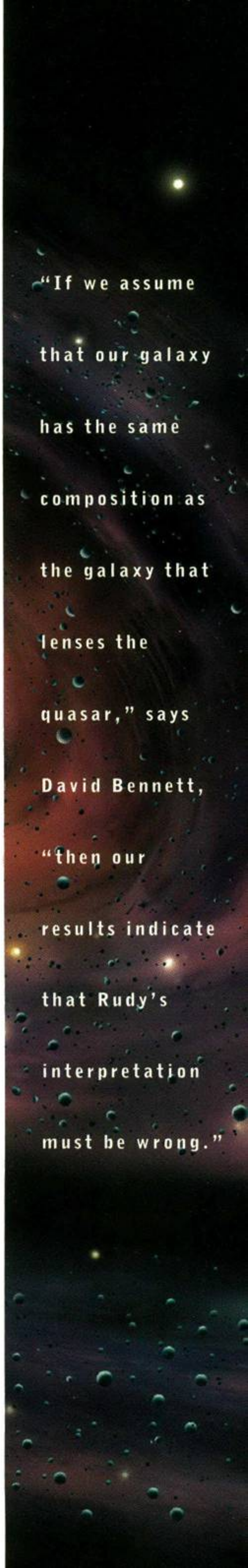


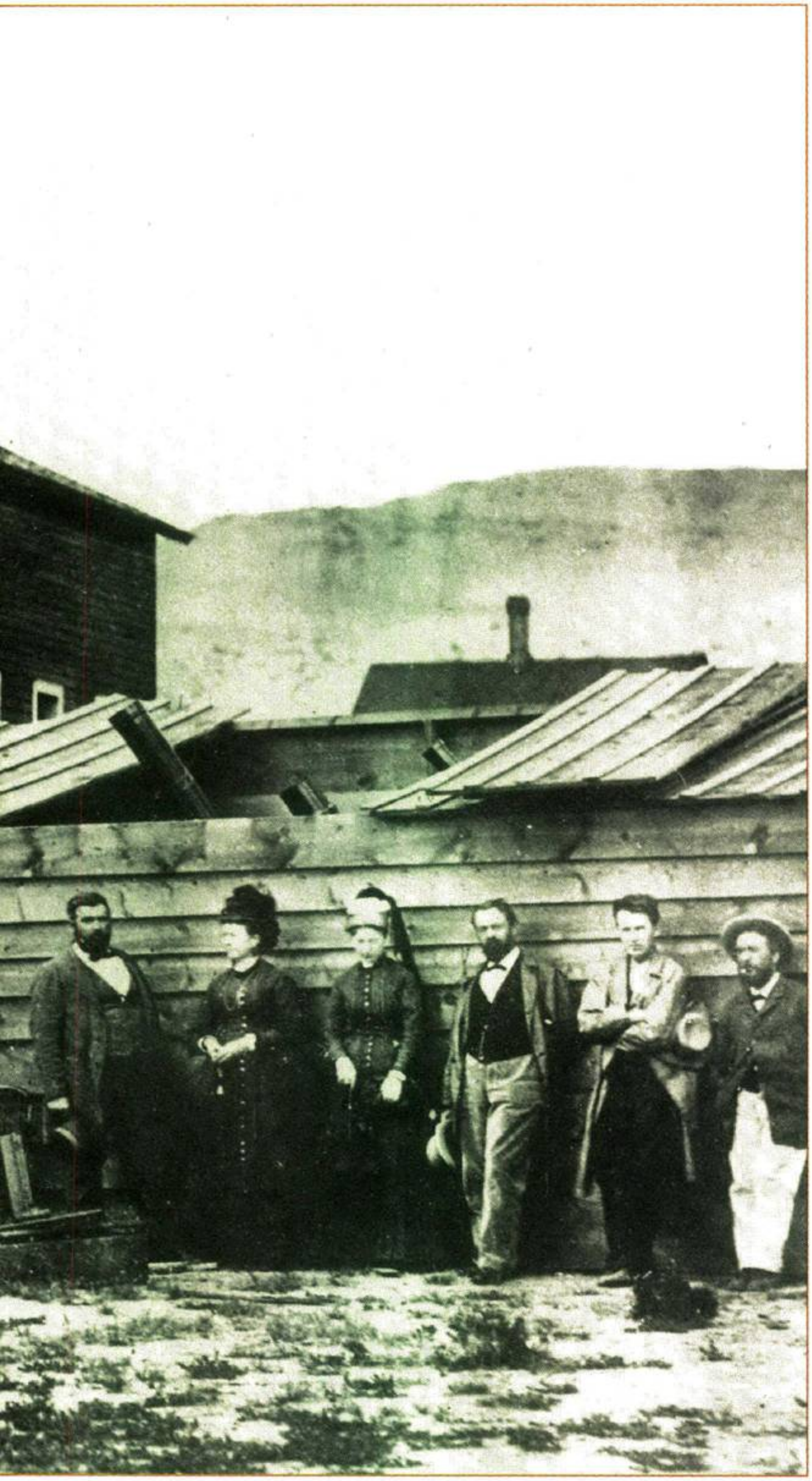
"If we assume that our galaxy has the same composition as the galaxy that lenses the quasar," says David Bennett, "then our results indicate that Rudy's interpretation must be wrong."

VULCAN

CHASERS

The Search for an Inside Planet

by William Sheehan
and Richard Baum



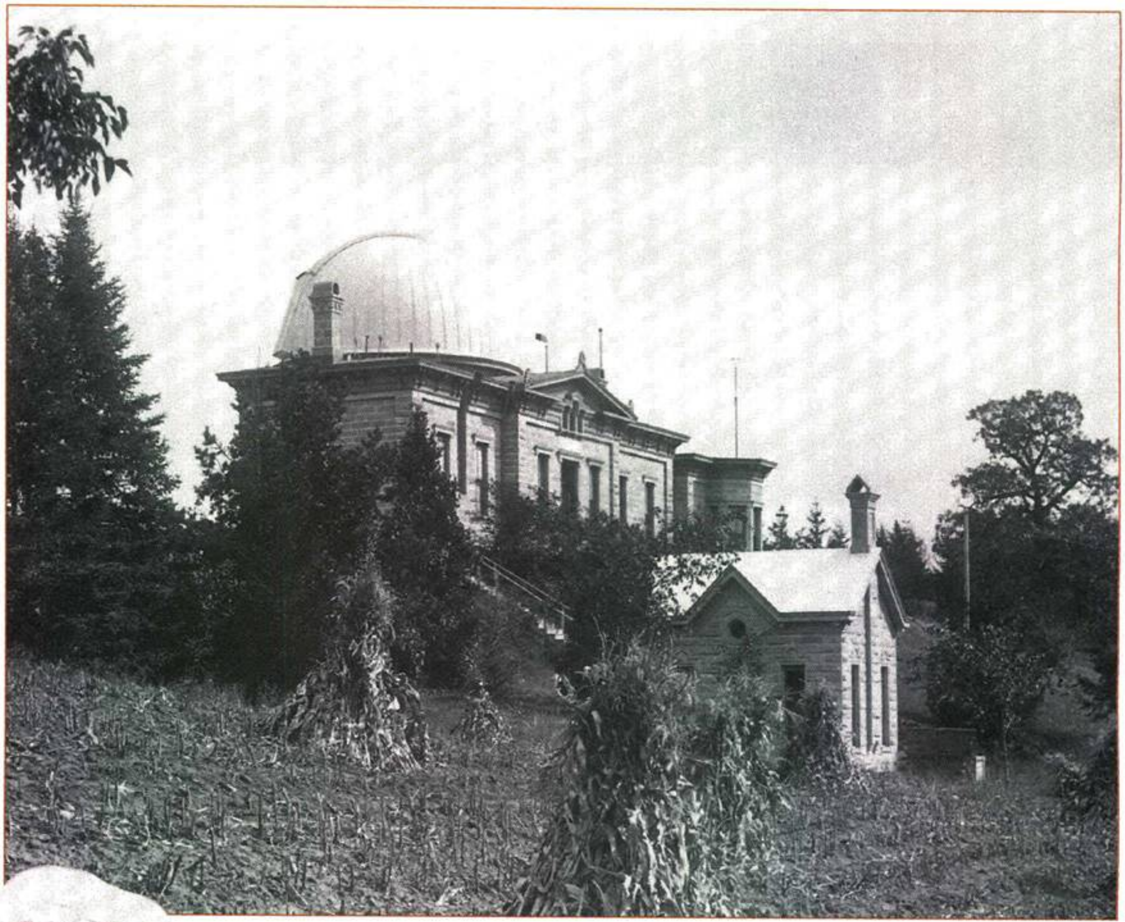
James C. Watson (sixth from right) and famed inventor Thomas A. Edison (second from right) sought Vulcan during an 1878 eclipse expedition to Rawlins, Wyoming.

The Mary Lea Shane Archives of the Lick Observatory

IN SEPTEMBER 1846, AT THE AGE OF 35, URBAIN JEAN Joseph Le Verrier of France stood at the pinnacle of the astronomical world. His calculations had led to one of the supreme discoveries of astronomy — Neptune, a giant world circling the sun in the frigid realm beyond Uranus, the hitherto most remote known planet. Neptune had been sighted by Johann Galle of the Berlin Observatory less than one degree from the position predicted by Le Verrier based on its gravitational disturbances of the motion of Uranus. The discovery was hailed as a remarkable vindication of Newtonian theory.

Now Le Verrier returned with confidence to another problem that had hung like a dark cloud over him. Having reordered the outer solar system he turned his attention to Mercury, on its inner edge. Mercury is a difficult object to observe because of its proximity to the sun. Some 13 times a century it passes in front of the solar disk and during these transits, its position relative to the sun can be measured with great accuracy — to within an error of only one arcsecond. Thus its motion is perfectly known. In the absence of the disturbing action of the other planets, the perihelion of its elliptical orbit — the point where it approaches nearest to the sun — would remain fixed unalterably in space. But the other planets pull on Mercury and cause the line between its perihelion and the sun to advance slowly forward. From an exhaustive analysis of the timings of Mercury's transits, Le Verrier found that the rate of precession was slightly faster than predicted by Newtonian law. The discrepancy was minute — according to Le Verrier's calculations, the planet completed one extra unexplained revolution every 3,000,000 years. Still, it was enough to suggest a crack in the foundations of celestial science.

By September 1859, Le Verrier had resolved to account for the unexplained advance of Mercury's perihelion using the same strategy that had led to

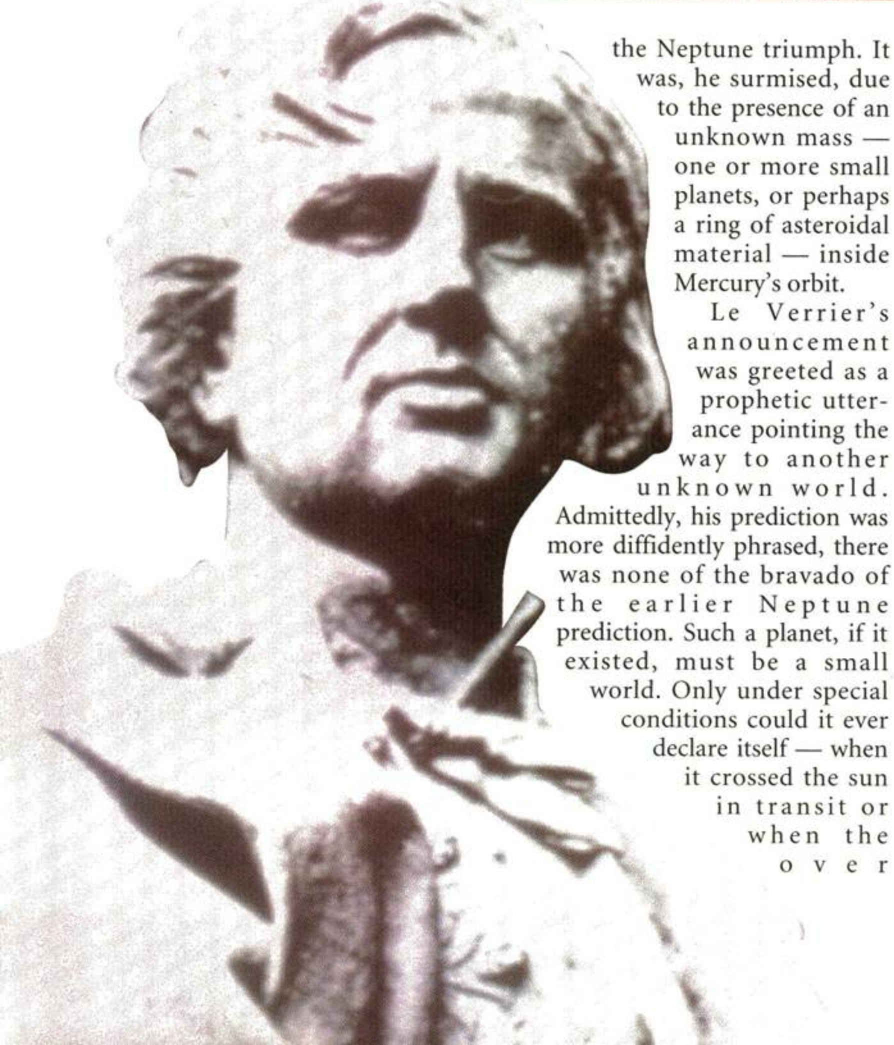


The small brick building in front of the Washburn Observatory housed Watson's 24-foot-long hole in the ground, from which he searched for Vulcan. The Shane Archives

the Neptune triumph. It was, he surmised, due to the presence of an unknown mass — one or more small planets, or perhaps a ring of asteroidal material — inside Mercury's orbit.

Le Verrier's announcement was greeted as a prophetic utterance pointing the way to another unknown world. Admittedly, his prediction was more diffidently phrased, there was none of the bravado of the earlier Neptune prediction. Such a planet, if it existed, must be a small world. Only under special conditions could it ever declare itself — when it crossed the sun in transit or when the overpoweringly brilliant disk of the sun was darkened in eclipse. Even then, it was hard to imagine how it could have been missed by earlier scourers of the sky, because the mass required to throw Mercury off its predicted course was apparently equal to that of Mercury itself. "How could a planet," Le Verrier wondered, "extremely bright and always near the sun, fail to have been recognized during a total eclipse? And would not such a planet pass between the sun and Earth, thereby making its presence known?"

There were good reasons for Le Verrier's diffidence. Astronomers had carefully watched the face of the sun ever since the invention of the telescope. A particularly thorough survey had been carried out by German pharmacist Heinrich Schwabe. Hoping to find an intra-mercurial planet, Schwabe, beginning in 1826, examined the sun's face every clear day he could — an average of about 300 days a year. He kept up his vigil for 12 years, recording every small spot that could be regarded as a suspect. During all this time he noted no new planets, though he did record something of even greater consequence: the 11-year sunspot cycle. He wrote



French mathematician Urbain Jean Joseph Le Verrier started the Vulcan *goose chase.* His calculations revealed a nagging, unexplained discrepancy in Mercury's orbital motion. Astronomical Society of the Pacific afterwards: "I may compare myself to Saul, who went out to seek his father's asses and found a kingdom."

Le Verrier had no sooner dropped his bombshell on the astronomical world when he received a curious response. A country doctor and amateur astronomer in the small village of Orgères-en-Beauce, Edmond Modeste Lescarbault, who for many years had been secretly pursuing his own quest for an intra-mercurial planet, claimed to have recorded it as a small black spot in transit across the sun. He made the observation on March 26, 1859, but communicated it to Le Verrier only in December. The master mathematician reacted with indignation — who was this amateur Lescarbault, and why had he remained silent for so long? Still, despite his skepticism, he could not put the matter out of his mind. On New Year's Eve, 1859, he decided to pay an unannounced visit to Orgères and walked 15 miles from the nearest train station to the doctor's house, easily distinguished by the cupola-observatory atop Lescarbault's office. He rapped imperiously at the door, and was greeted by a shy little man — a case of the lion and the lamb. The Parisian put a series of probing questions to Lescarbault. After about an hour he left satisfied Lescarbault could be trusted; he returned to Paris convinced — as he would remain for the rest of his life — of the reality of the new planet. He and Lescarbault apparently never met again.

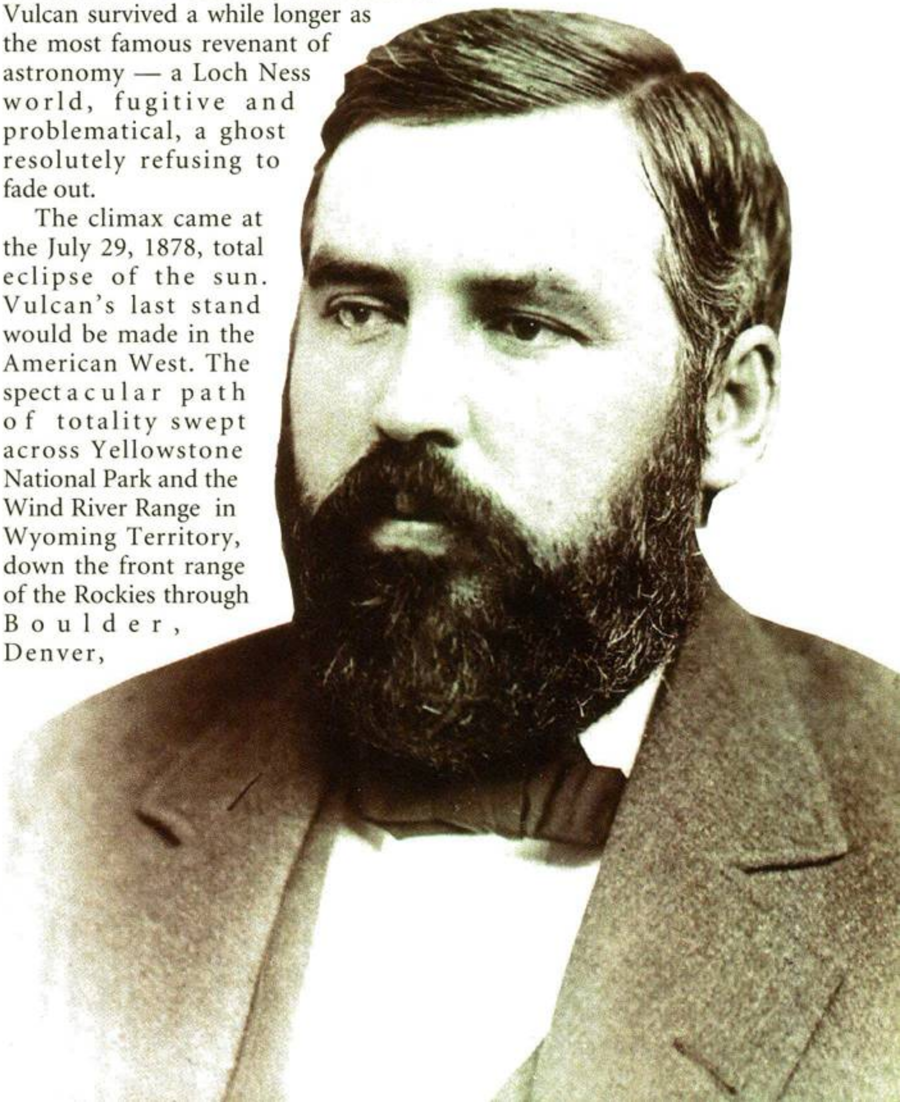
The planet was duly given a name, Vulcan, after the Roman god of fire. It soon became "the only topic of converse at the seances of philosophy and the salons of fashion. Garibaldi and the weather were no longer of interest; and the village doctor, in his extempore observatory . . . were the only subjects of discussion." The shy little doctor, at Le Verrier's insistence, was awarded the Legion of Honor by Napoleon III, while Le Verrier was acknowledged as one of the great heroes of science and received the adulation of an awestruck world.

But then, unexpectedly, Vulcan began to fizzle. Le Verrier suggested that it ought to transit the sun once or possibly twice in late March or early April, also in late September or early October, each year. Beginning with its next predicted transit, in March 1860, it failed to keep its scheduled appointments. Nor did it register an appearance at the July 1860 total eclipse in Spain. Disappointment grew into disillusionment, and Vulcan became suspect. "I refuse to go on a wild goose chase after Le Verrier's mythical birds!" declared astronomer C. H. F. Peters of Hamilton College, New York, at the eclipse of 1869.

Whether irritation at Vulcan's failure to show itself had anything to do with Le Verrier's increasing reputation for ill-temper is unknown. Certainly he was much feared by his subordinates at the Paris Observatory. In appearance, he was "a decided blond, with light chestnut hair turning gray, slender form, shaven face, rather pale and thin, but very attractive, and extremely intellectual features." But his personal manner was less attractive than his features. One colleague described him as a *mauvais coucheur* (a bad bedfellow), while an English scientist who wanted to meet him during a visit to Paris was warned: "I do not know whether M. Le Verrier is actually the most detestable man in France — but I am quite certain that he is the most detested." After his staff threatened to resign in 1870, he stepped down as director of the Paris Observatory, but returned to power after his successor, Delaunay, died in a boating accident. (Delaunay had an extreme phobia of water, as both his father and brother had drowned. He crossed the English Channel only once, in order to accept the gold medal of the Royal Astronomical Society. In autumn 1872, he departed from his usual caution and accepted an impromptu invitation to go sailing; immediately a sudden squall came up, and the boat, with the unfortunate Delaunay on board, was lost.)

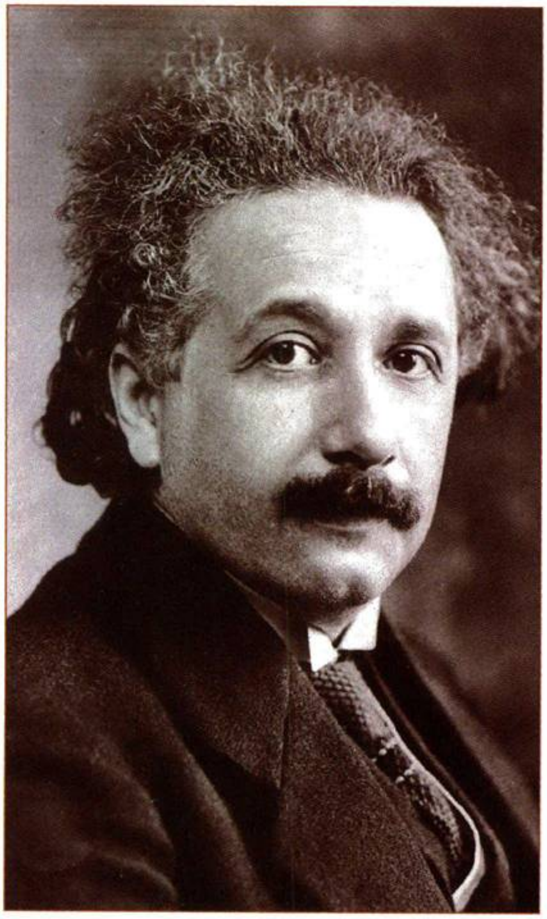
When Le Verrier died on September 23, 1877 — the anniversary of the discovery of Neptune — Vulcan was qualified with a question mark and skepticism was widespread. Still, many astronomers held out hope since there was no obvious alternative for unraveling the troublesome matter of Mercury's motion. So Vulcan survived a while longer as the most famous revenant of astronomy — a Loch Ness world, fugitive and problematical, a ghost resolutely refusing to fade out.

The climax came at the July 29, 1878, total eclipse of the sun. Vulcan's last stand would be made in the American West. The spectacular path of totality swept across Yellowstone National Park and the Wind River Range in Wyoming Territory, down the front range of the Rockies through Boulder, Denver,



James Craig Watson searched for Vulcan at the bottom of a 24-foot-deep underground shaft.

The Shane Archives



Albert Einstein's general theory of relativity brilliantly solved the Mercury mystery. Vulcan was no longer necessary.

Yerkes Observatory

and Pikes Peak, then across Oklahoma Indian Territory into Texas and Louisiana. Among the astronomers in pursuit of the planet was Simon Newcomb of the U.S. Naval Observatory, who observed at Separation, Wyoming, a railroad station in a dull, nearly uninhabited sagebrush-covered plain with a view bounded by the distant peaks of the Rockies. He was joined by University of Michigan astronomer James Craig Watson, a heavy-set man nicknamed "Tubby" by Ann Arbor undergraduates, and renowned for his mastery of celestial mechanics and his score of asteroid discoveries.

On the morning of July 29, the sky throughout Wyoming was, as a local paper reported, "as slick and clean as a Cheyenne free-lunch table." In the early afternoon, as the three minutes of totality began, Newcomb used a small telescope to sweep the space east of the sun. Watson, using a four-inch refractor, confined his search to a narrow zone on either side of the sun 15° long by 1½° wide. Possessed of a phenomenal memory which had won him a reputation as a lightning calculator, Watson had previously memorized the positions of all stars on a map of this zone down to seventh magnitude. Thus he got over the ground quickly. He covered the sky east of the sun where Newcomb was roving, then began sweeping to the west; between the sun and Theta Cancri. He came across "a ruddy star," not on the map, of about magnitude 4.5. Resuming his sweep even farther west, he came across another, even brighter red star, hurriedly marked its position, and ran over to Newcomb to try to get him to verify it. Newcomb, alas, was absorbed in tracking down his own planet suspect — a mere star, it later proved. Then suddenly the eclipse was over.

Watson, unquestionably a skilled observer, was convinced that he had seen one, possibly two, intra-mercurial planets. However, his observations were later criticized by Peters, who suggested he had made a simple mistake and incorrectly marked the two stars Theta and Zeta Cancri, "haste and excitement doing the rest."

Watson refused to give up and spent the rest of his life pursuing his Vulcan obsession. After leaving Ann Arbor to supervise the building of the magnificent Washburn Observatory at the University of Wisconsin in Madison, he became, literally, a man with tunnel vision. He planned to track down Vulcan in broad daylight with a telescope located at the bottom of a 24-foot-deep shaft dug into a hill near Lake Mendota, hoping the shaft would act like an enormous dew cap and allow him to see stars near the sun against the bright sky. (The idea dates back to Aristotle, who once commented that stars could be seen during

Christian Heinrich Friedrich Peters remained skeptical of Vulcan's existence, declaring "I refuse to go on a wild goose chase after Le Verrier's mythical birds!"

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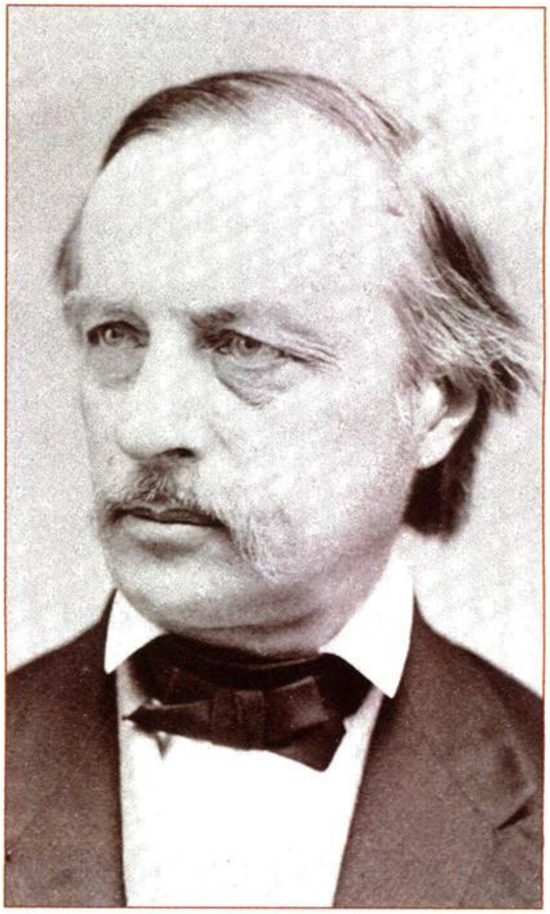


Astronomers traveled to Caroline Island in the central Pacific to search for Vulcan during an 1883 solar eclipse. Astronomer Edward S. Holden wears the checkered shirt.

The Shane Archives

the daytime from deep wells; however, it had been debunked many times before Watson tried it.)

James C. Watson died in November 1880 before the project was finished. He fell to complications of pneumonia contracted during the harsh Wisconsin winter — not, as rumored, while burrowing in the underground observatory but rather while supervising the installation of a furnace in the nearby director's house.

When his successor, Edward S. Holden, arrived in Madison the following spring to finish work on the underground observatory, Peters warned him: "One thing I would beg you most earnestly: Do not sit in that subterranean hole, to watch until Vulcan passes. Not that I apprehend you might discover him . . . but it might deadly ruin your health, and you better fill up the hole." Holden made a few observations in order to satisfy himself that it would be impossible to observe Vulcan by daylight — it was impossible — and the underground observatory was abandoned forever. In the 1930s, the tunnel was deemed a hazard by the university's building and grounds department and filled in; in the 1940s, the building was torn down completely. There is no longer any trace of it.

After Watson's death, Vulcan's fortunes fell, never to recover. The advance of Mercury's perihelion was brilliantly explained by Albert Einstein in November 1915 at his desk in Berlin — his general theory of relativity finally exorcised the ghost of Vulcan from the inner solar system. Einstein presented a new theory of gravitation that conceived of it as a warping of the fabric of space-time. According to his theory, Mercury should precess slightly faster than the Newtonian rate — by 0.1 arcseconds for each orbital revolution of the planet, or 43 arc-seconds per century. This agreed exactly with the observed rate. Vulcan became redundant.

Nevertheless, Watson's observations at the 1878 eclipse have never been fully explained. Peters may well have been right in supposing that he had simply misidentified known stars, but a more intriguing possibility is that he saw a pair of small sun-grazing comets such as those recorded by satellites in recent years. The mystery remains.

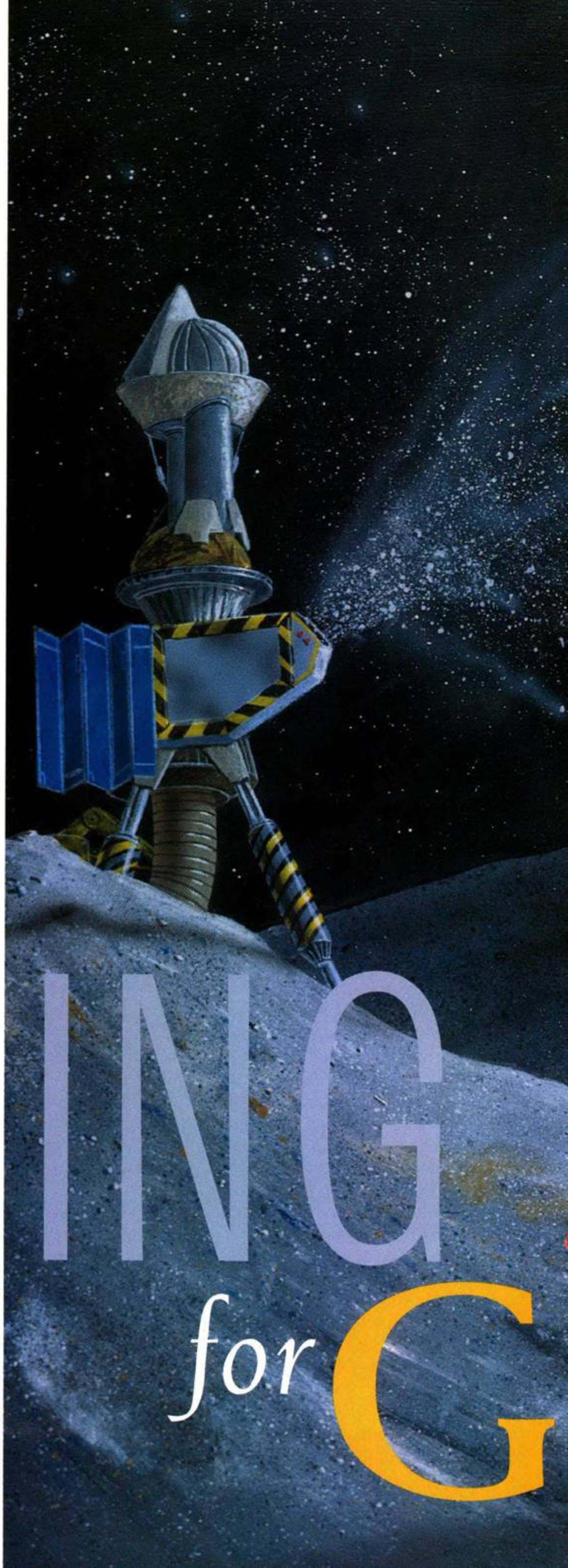
Though now almost forgotten, Vulcan, the planet that never was, reminds us that those who seek do often find. Dead-end though it proved to be, Vulcan is more than a ghost; it is a reminder of discoveries — Schwabe's sunspot cycle and Einstein's theory of gravitation — far more important than the fugitive speck of matter that astronomers long dreamed of capturing on the inner edge of the solar system. A

William Sheehan and Richard Baum co-authored In Search of Planet Vulcan: The Ghost in Newton's Clockwork Universe *(Plenum Press, 1997).*

DIGGING for G

Entrepreneurs searching for solar-system riches may not have all that far to go.

Jeffrey S. Kargel

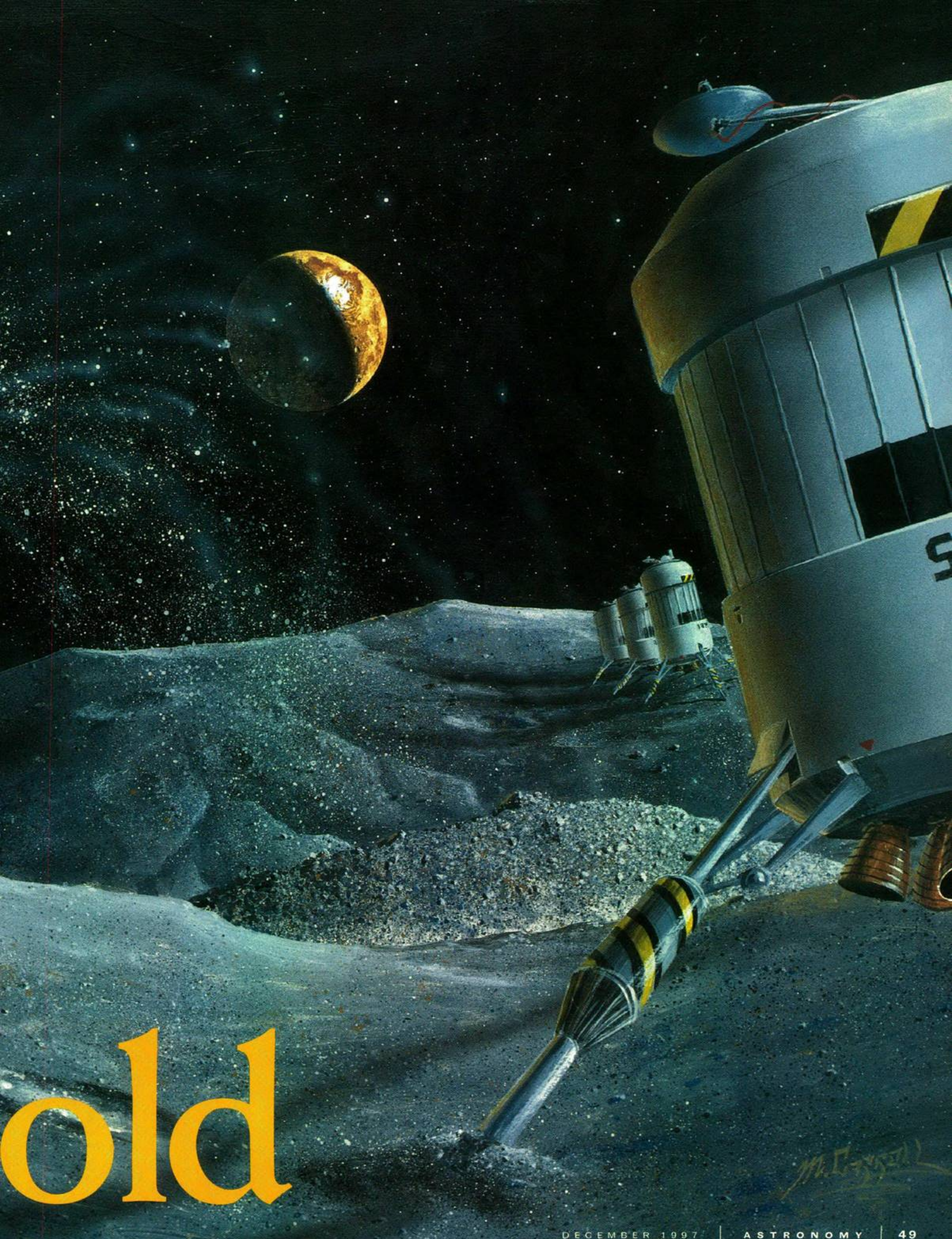


Michael Carroll

LAST DECEMBER, A WEEK AFTER A REPORT THAT ICE exists at the moon's south pole, engineers, scientists, corporate managers, and NASA planners assembled in a conference hall outside Houston. Our objective: to create a long-term strategy for developing space resources. This eventually might make the icy lunar south pole (among other extraterrestrial lands) "the most valuable real estate in the solar system," as one participant put it. The charting of extraterrestrial resources is now part of NASA's new quest "To Chart Our Destiny," one of three quests in NASA's Roadmap for the next two decades (the others are "The Origin of Life and its Existence beyond Earth" and "Solar System Formation and Evolution").

One meeting participant, Apollo 17 astronaut Jack Schmitt, had explored lunar valleys in his zeal to support NASA's grand vision of human space exploration. Now he was seated across the room. I reflected for a moment on John F. Kennedy's 1961 challenge, "before this decade is out, to send a man to the moon and return him safely to the Earth." I recalled the dusty gray moonscape shown by Apollo 8's live Christmas Eve telecast from lunar orbit, a moment of my childhood engraved in my memory for a lifetime.

Space mining has modern roots in work done 20 years ago by Michael Gaffey, Brian O'Leary, and others. But at that time, developing space resources was far-fetched science fiction to anyone hoping for a quick financial return. Since then, John Lewis has done more than anyone else to make space resource development a vibrant field of research and development. These researchers are meteoriticists, astronomers, and cosmochemists — they understand that most meteorites are pieces of asteroids; they recognize that some near-Earth asteroids (NEAs) are easier to reach and far easier to return material from than our own moon. Lewis and others have studied how to develop two types of raw materials: those that are rare, valuable, and being depleted on Earth but plentiful in space and those that are common both



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AT RECENT MARKET PRICES, THE METALS IN

on Earth and in space but are expensive to launch from Earth and vital to space colonization and resource development.

Four developments have brought space mining into industry's grasp. First, professional and amateur astronomers have discovered more than 400 NEAs, plotted their orbits, estimated their sizes, and (for a few) determined their compositions. David Rabinowitz and Eugene Shoemaker have estimated that 2,000 NEAs larger than 1 km across exist. Second, the monopoly on deep-space launches once held by Cold-War superpowers has been broken by competition from space agencies in Europe, Japan, and Russia and by private launch services, reducing the cost of access to space.

Third, technological advances and the transfer of military technology following the Cold War have led to advances in materials, computers, robotics, and deep-space propulsion. Finally, streamlined management of federal space projects has reduced the costs of solar system missions. Government projects such as Clementine, Discovery, and New Millennium serve as models for cost-conscious corporate managers of space technology projects. Robotic missions now cost one-fourth of what equivalent projects cost six years ago; other missions impossible then are practical now. The net effect is that robotic space mining is now a concept that dollar-minded businessmen can consider.

Space Treasure

People have found uses for virtually every accessible material. Human habits and industry have exploited large amounts of abundant, inexpensive substances (such as sand and gravel) and small amounts of rare, costly ones (such as gold and platinum). Space resources and space industrialization may revolutionize the way we do things on Earth and in space and enhance the quality of life on this planet. In a future without space mining, we will ultimately either be forced to exploit difficult new sources of energy and minerals or have to live with diminishing supplies and their eventual depletion.

Lunar rocks and soils may be the first targets of commercial space mining. Volcanic glass spherules and other materials, such as these Apollo 16 samples, could make jewelry, watches, and other items.

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Jeffrey Kargel

The availability of metals currently depends on how abundant they are in Earth's upper continental crust, the chief reservoir of our metals. Earth's core will forever sequester 99.9 percent of our planet's gold, rhenium, and platinum-group metals (or PGMs: platinum, palladium, iridium, osmium, rhodium, and ruthenium). They have very low abundances in Earth's upper continental crust — and thus are very valuable — because most sank into the interior as the core was forming.

Some metallic asteroids have roughly the same abundance of gold and PGMs as does Earth's core. These objects, the cores of larger asteroids shattered by huge impacts, are not all equal, however. Besides having a wide range of sizes and lying at different distances from Earth, they vary greatly in PGM and gold abundance. This makes the hunt for the richest metallic NEAs a challenge, but one worth the effort.

The study of iron meteorites tells us that the first material to solidify in the cooling cores of some asteroids is extraordinarily rich in PGMs — 100 to 200 parts per million in some cases. On Earth, we mine deposits typically containing 2 ppm of gold, and narrow veins containing 30 ppm of precious metals are exceptional.

I have modeled how exploiting such an object could affect production rates and market prices. A metallic asteroid 1 km across containing 185 ppm of PGMs, rhenium, germanium, and gold would have 780,000 metric tons of precious metals. At recent market prices, these metals would be worth over $10 trillion (nearly the gross domestic product of the United States for a year). Importing this much metal over a period of 50 years would cause precipitous drops in the market value of these metals; the total market value would decline to about $900 billion total, or $17.7 billion per year. As asteroid mining builds over the next century, the result for people on Earth may be a new metallurgical revolution as metals such as platinum, palladium, and iridium become abundant and relatively inexpensive. The price of iridium, for instance, may fall to between the present values of silver and copper.

Ordinary chondrite asteroids, which never melted extensively or formed a core, contain a cosmic abundance of precious metals scattered in grains rich in iron and nickel. Although concentrations of precious metals in this type of asteroid aren't as high as in some metallic ones, robotic asteroid miners could have an easy time with ordinary chondrites. Electromagnets could scoop up and separate the metal from the asteroid's soil, a simple

A METALLIC ASTEROID 1 KM ACROSS WOULD BE WORTH MORE THAN $10 TRILLION.

task where gravity may reduce a 60-ton load of metal (equivalent to an M-1 tank) to less than 60 pounds.

Water in space will be crucial for the space economy within 20 years. Besides providing water for humans and agriculture in space colonies, water can be electrolyzed to yield hydrogen and oxygen for rocket propellants, chemical industries, and fuel cells to power vehicles and mining equipment.

Superheated water also can be used to propel "steam rockets," an efficient way to move large masses through interplanetary space. Water will be shipped into low-Earth orbit to help boost satellites to geosynchronous orbit and to place mining and transport equipment onto trajectories to the moon and asteroids. If ice is as abundant at the moon's south pole as some scientists think, it likely will be the first extraterrestrial water to be mined. A more valuable source of water in the long run will be carbonaceous chondrite asteroids, in which chemically bound water makes up 1 to 20 percent of their mass. Because NEAs have little gravity and some have orbits similar to Earth's, it takes less energy to deliver mass into low-Earth orbit from some of them than it does from the moon.

NASA/JPL

The main-belt asteroid Ida is a stony or stony-iron object that could be mined. An asteroid just 1 km across, like Ida's tiny moonlet, Dactyl (left), could supply a million tons of precious metals.

A Market for the Moon

The potential markets for the precious metals and water in asteroids are huge, but they pale beside prospects for a rare isotope of a common gas. Helium-3, essential in a virtually pollution- and radiation-free type of fusion energy production, was lost by Earth early in its history. It occurs in other space objects, however, notably our moon.

The sun emits a tenuous wind of ionized hydrogen and helium that blows through space and hits any unshielded object. Earth's magnetic field and atmosphere shield us from this solar wind, but the moon is exposed. Over billions of years, the lunar soil has been impregnated with loads of helium-3. Jeff Johnson of the U.S. Geological Survey has produced a model that predicts the abundance of helium-3 on the moon based on the age and type of soil and on the local intensity of the solar wind. His study may offer a treasure map for robotic helium prospectors, which may head for Johnson's helium hotspots in the farside basins Mare Orientale and Mare Moscoviense to supply Earth's energy market, which already is on the order of a trillion dollars a year.

Silicon, germanium, arsenic, selenium, indium, gallium, and phosphorus mined from metallic asteroids may be used to help fabricate thin-film photovoltaics that are both lightweight and flexible. These efficient devices could be used in the construction of solar-power plants in Earth orbit (which would beam the energy they generate to our planet) and on or near the moon, Mars, and asteroids (to power mining and human bases) should efforts to make fusion energy practical fail.

Tests in the Space Shuttle's Wake Shield Facility have already shown that photovoltaic arrays five microns thick can be manufactured in space. Calculations suggest that it may be cheaper to use space-derived materials to build large power stations in space than to launch everything from Earth.

Several space missions are well equipped to explore for space resources. Lunar Prospector, scheduled for launch in November, will provide improved estimates of the distribution and amount of ice at the moon's south pole, map mineral abundances to help prospectors find sources of chemically bound oxygen, and improve the helium-3 map. Mars Global Surveyor arrived at the Red Planet last September and will soon begin mapping the distribution of ice and other minerals on Mars.

NASA's Near-Earth Asteroid Rendezvous mission, launched in February 1996, is almost halfway to the NEA Eros. There it will go into orbit and make a detailed mineralogic and visual map and perhaps touch down briefly. In the late 1990s, the Japanese space agency plans to send the world's first asteroid sample-return craft to the NEA Nereus, where it will acquire a sample by shooting the asteroid and catching the ejected debris as it flies past. Recently Japan agreed to piggyback a NASA microrover on their mission.

PART OF THE SOLUTION TO OUR LIMITED RESOURCES IS TO LOOK TO OTHER WORLDS

Space Biz

Like many at the conference, I grew up believing that massive government spending was vital to space exploration and development. In the Apollo days, this was true. After NASA's Apollo-era experimentation with satellites for communications, remote sensing, weather monitoring, and navigation, space commercialization intervened and created new industries in these areas. Along with new private launch services, these commercial activities are worth four times NASA's budget. With direct-TV broadcasts, mobile remote communications, and GPS navigation for automobiles entering our daily lives, the prospects for growth in the low-Earth-orbit and geosynchronous operations of the commercial space sector seem boundless.

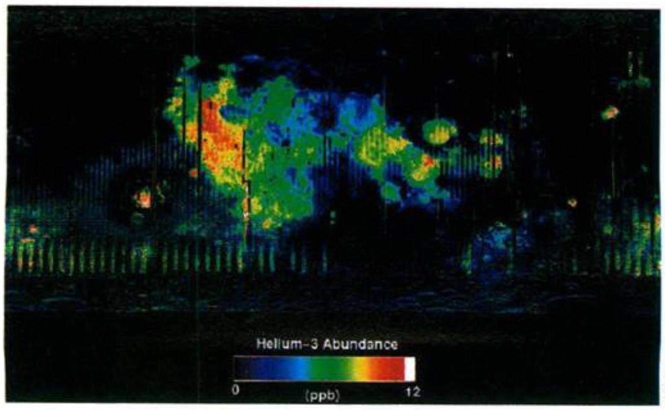
Proponents of the ambitious Space Exploration Initiative of the late 1980s had pleaded that it would re-establish American technological supremacy, build a strong economic future, instill purpose and pride in young Americans, and change the world's future. No doubt it could have — for $400 billion. But the budget battles between Congress and the first Clinton administration proved that nothing like the Space Exploration Initiative can be contemplated.

A new approach to the same dream is emerging. We do not want to revisit the moon merely to photograph boot prints, or visit Mars simply to decorate the red soil with Old Glory. We will use space rocks to build a vibrant new economy linking Earth and space. Some participants at the meeting have already started their own companies to ride this new wave of space industrialization. Last December's conference was not primarily a science or engineering conference, nor was it a meeting of a sci-fi cult. Above all, it was business.

The large-scale development of space resources may require launch costs to fall by a factor of three over the next take 15 to 20 years. NASA's realistic objective is to bring the cost of placing one kilogram in low-Earth orbit down even further, to $1,000. Work toward this goal is under way — within a few years, launch costs should decline by 30 percent thanks to the next-generation single-stage-to-orbit launchers now being developed.

Engineers and scientists from many companies, universities, and national labs across the United States are studying how to produce water, oxygen, and hydrogen from lunar, martian, and asteroidal materials. The recent discovery that ice may exist in shadowed areas near the moon's south pole may make the task easier or at least more certain. Hauled to low-Earth orbit, asteroidal or lunar water may satisfy markets that already would be worth billions of dollars annually.

The most valuable space resource could be helium-3, a rare form used to generate fusion energy. Hotspots for helium-3 (in yellow and red) on the moon's surface include Mare Orientale and Mare Moscoviense.



Jeff Johnson

The first small-scale demonstration of rocket fuel production using indigenous martian resources may be attempted during a NASA Mars mission in 2001. Later missions may depend on this technology for the return to Earth of martian rock samples. A sample-return craft would be sent to Mars with ascent stages unfueled. During about 18 months on the surface, a microrover could collect geologic samples and load them onto the return craft. Meanwhile, the fuel tanks would be filled using methane produced by the chemical reaction of hydrogen brought from Earth with carbon dioxide from the martian atmosphere. Many more martian rocks could be returned using this innovative strategy than if all the propellants were hauled from Earth. Ultimately, water from martian ice or minerals will be used for martian exploration.

Other conference participants are planning more modest but more near-term space development activities. Harvest Moon, Inc., plans a privately financed, commercial mission to return samples from the moon. The company's director, Brad Blair, considers this project the world's first attempt at commercial mining of extraterrestrial resources. Although the long-term value to society of moon rocks sold as jewelry and collectors' items may be minimal, the scientific value of rocks from an additional lunar site is substantial. A consortium involving Lunacorp and Carnegie Mellon University plans to send two rovers to the moon and market opportunities for pay-per-drive (by telepresence) to theme park visitors. According to David Gump, Lunacorp president, they will launch the rovers in 2000, land near the Apollo 11 site, and over a period of several months drive the rover to other historic places. The direct participation of the public in these and other projects may finally break the paradigm of big-government deep-space missions.

If these projects are successful, then space industrialization and humankind will be one giant leap closer to the stars. The word is out — if you want to cross the bridge into the 21st century of space mining, then space must pay its way and give private investors a handsome early return on investment. According to the still-developing policy, government will do what it is able to do. It can make access to space less expensive, support Earth-based detection and spectroscopic study of asteroids, launch pioneering probes to map resources, and develop a few key technologies central to space mining.

Some space development enthusiasts hope for government tax breaks and limited matching funds for space developers. Government also could offer political support in the international arena to back mining claims for those who put capital on the line. But the Federal Treasury will not be a limitless cash cow, and the Internal Revenue Service will not be the patsy of big business. Government incentives will have to result in a return to America, and the world, of something immeasurably valuable — a bright future for our sons and daughters, a breath of fresh air for their children, and maybe greater tax revenues for the IRS. Government policy can facilitate space development, but private industry and investors will do the real work, take the greatest risks, and reap the biggest profits.

NASA/JPL

When the Galileo spacecraft flew by mineral-rich Gaspra in 1991, it marked the first asteroid ever viewed from up close. One day, asteroids could provide significant resources for a mineral-depleted Earth.

Mining Policy and Law

In any case, the role of government will be smaller than it has been in the nation's past. Many public incentives helped expand and spur development on the American frontier. The Louisiana Purchase of 1803 overnight doubled the territory of the United States for a $15-million payment to France in cash and assumption of debt. This was followed by the Lewis and Clark Expedition (1804–1806), financed and officially charged by President Jefferson and Congress to map the Northwest Passage. The Lewis and Clark Expedition proved that the Northwest Passage was a myth, but it also began mapping the rich resources of the Louisiana Territory.

After two generations of political wrangling, President Lincoln and Congress finally decided how to distribute the vast public holdings of the American West. The Homestead Act of 1862 granted 160 acres of public land for a small fee to anyone able to cultivate or otherwise improve the land and survive there for five years. To encourage mineral development on the frontier, Congress passed the General Mining Law of 1872, which permitted royalty-free claim staking and prospecting on all federal lands not protected as park or wilderness. Between 1870 and 1900, such federal provisions encouraged the settling, mining, and cultivation of 430 million acres of once-public land, representing 40 percent of American territory improved since Jamestown. Although the tremendous human and environmental costs of this westward expansion weren't recognized by the American government until it was too late, the magnitude of the long-term consequences of the frontier legislation can hardly be overestimated. Development of the frontier transformed America into an industrial superpower.

Amidst the industrial revolution and at the heyday of American iron-ore mining, Andrew Carnegie recognized the need to consider poorer deposits and access new reserves. Concerned with the steady depletion taking place before his eyes, he stated, "Our once supposed ample supply of rich ores can hardly outlast the generation now appearing, leaving only the leaner ores for the latter years of the century."

What Carnegie couldn't imagine was that part of the solution might be found on other worlds. It is not merely that other worlds present us with fresh, unexploited lands, but that these other worlds have evolved differently from our own and consequently have mineral deposits of types that have never existed on Earth. In accordance with the Outer Space Treaty of 1967, the United States, Russia, and many other countries do not accept national sovereignty over extraterrestrial lands, although this treaty does not forbid recovery and profitable uses of the resources of outer space.

The United States government has a tradition of stimulating mineral development through official policy, including purchases of strategic stockpiles of minerals vital to national security, government-sponsored technology development, and tax incentives. Although some other federal actions to stimulate economic production in the West had deplorable consequences for the environment and many Native American cultures, the fact is that the United States government was highly effective in achieving its goals; once the resources of interest had been identified and the technological capability and infrastructure to subdue the Wild West had been created, all that was needed was the policy to induce the West's development. This time, development of the new frontier will generate positive global environmental and human impacts on the home front and on the frontier. ▣

Jeffrey S. Kargel is a planetary scientist at the U.S. Geological Survey in Flagstaff, Arizona. He wrote "The Ice Ages of Mars" for the December 1992 issue of Astronomy.

ASTRONOMY'S
Feisty Old Man

Allan Sandage, the heir to Edwin Hubble's legacy,
wages a lonely battle against his critics.

by Frederic Golden

THESE ARE DAYS WHEN THE GREATEST LIVING observational cosmologist, or SuperHubble, as Allan Sandage has been called, ought to be feeling on top of the world — maybe even the universe. After all, the latest findings seem closer to his views on the scale and distance of the cosmos than those of his long-standing critics. But Sandage — whose middle name is Rex — doesn't think of himself as king of the mountain anymore.

At age 70, he sees himself as a "grumpy old man," an outcast in his very own field, which he has served with distinction for nearly half a century, starting with his days as heir apparent to the lordly Edwin P. Hubble. But all that, he says, has been forgotten. "Ninety percent of America's astronomers think I'm a has-been, totally out of touch, like the dinosaurs."

Even recent data from the European Space Agency's Hipparcos satellite bolstering his long-held positions do not cheer him. "Means nothing," he snorts. "The media says the data show that the two sides are coming together, but that's not true. We've stayed rock bottom with our numbers all along." Indeed, when I call upon him in his cluttered office at the Carnegie Observatories' venerable headquarters in Pasadena, California, he is still fuming about a referee's report he's just received about his commentary on an early interpretation of the Hipparcos results. The referee wants him to drastically overhaul it. But Sandage indignantly refuses: "I've said to the editor, you either accept the premises on which we've written this, or reject it. We're not going to change the premises."

When I profess disbelief at his protestations of being astronomy's forgotten man, he fixes me with the same piercing gray eyes that long scanned the distant universe with Palomar's 200-inch mirror, for decades the world's preeminent telescope. "You don't believe I'm considered a dinosaur?" he snaps. "Well, I suggest you call (he names a prominent astronomer), she'll say you should not have talked to that man." (Later, when I tell her what Sandage said, she laughs, "Oh, I'm not going to rise to his bait.")

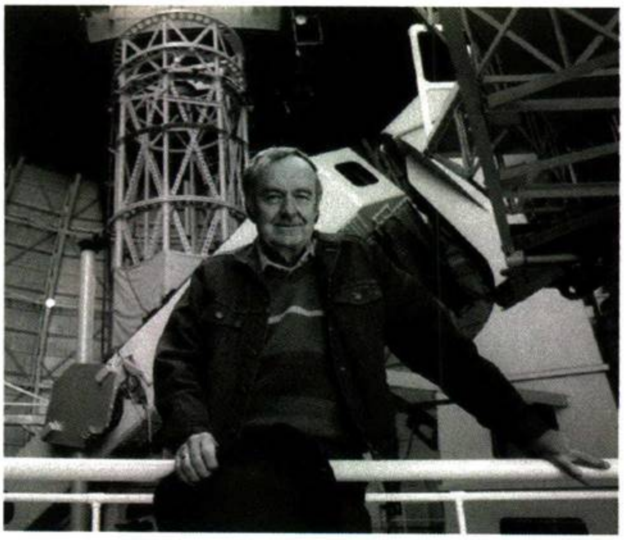
Allan Sandage stands by the famous 100-inch Hooker Telescope atop Mt. Wilson. Even at age 70, he continues to fight the Hubble Wars over the expansion rate and age of the universe. Frederic Golden

Sandage's feistiness is legendary in astronomical circles. For years, he refused to speak to his onetime crony and old Caltech classmate, Halton C. Arp, even though they shared offices in the same corridor before Arp moved to Munich. "I don't even remember the specific issue," admits Sandage, who now considers Arp a close friend, "but we'd grown so far apart in our professional views there just didn't seem to be any point to talking." Though the second youngest member ever elected at the time, he quit the National Academy of Sciences after its rejection of his friend, Olin J. Eggen ("The best stellar astronomer in the last 30 years," he says).

More recently, he has been on barely more than nodding terms with Wendy Freedman, another Carnegie observer who he puts in the "enemy" camp (although Freedman says, "He is one of the most brilliant minds in observational astronomy in this century"). Nor will he go to meetings if he feels they'll be dominated by his opponents. "It does no good whatsoever, no good whatsoever," he repeats melodramatically, like a refrain from the Wagnerian operas he loves. "So I've isolated myself completely. I've become a hermit."

Yet under the curmudgeonly exterior, there is a man of considerable charm and old-fashioned courtliness. His complaints are laced with self-deprecatory "aw-shucks" humor. He professes to hate the media. "I don't know why I'm even talking to you," he says several times, even as he goes right on talking. He tells me about his long, happy marriage to his wife Mary, who dropped out from astronomy to rear their two sons, David and John; the idiosyncrasies of Hubble and some of the other

"Ninety percent of American astronomers think I'm a has-been, like the dinosaurs."


Sandage, seen here with the Hooker Telescope in 1984, has consistently measured lower values for the Hubble constant than have most other astronomers. Doug Cunningham

astronomers with whom he has worked; his almost mystical belief that "there must be some organizing principle" out there; and his wish to live in contemplative isolation, like a Trappist monk. Yet, as we lunch at Pasadena's chic Parkway Grill, he banters jovially with the staff like an old pol. Later, as he guides me around the Mount Wilson Observatory, the would-be recluse is welcomed as warmly as a triumphant Caesar back from the Gallic wars.

Sandage is still in the thick of battle. The combat, named the Hubble Wars, is only intellectual. But it's warfare just the same. What's at stake is nothing less than vindication on the central questions of cosmology: the age, size, and perhaps even the fate of the universe. And that would mean a place in astronomical history, right up there with Galileo, Herschel, and his mentor, Hubble.

Not that Sandage's reputation needs burnishing. In 45 years at Carnegie — he retired September 1 — he has made innumerable contributions, from deepening our understanding of the evolution of stars and galaxies to spotting the first quasar. These efforts have been acknowledged with a fistful of honors, including the Eddington Medal of the Royal Astronomical Society, the National Medal of Science, and the Royal Swedish Academy of Sciences' Crafoord Prize, a $325,000 award for achievements in fields not recognized by Nobel Prizes.

Sandage stopped stargazing three years ago ("after 30 years of observing 100 nights a year"). He began feeling wobbly on those vaulting platforms high above the big mirrors. Besides, all that new electronic gadgetry — CCDs, digital storage devices — has made his skills with his treasured glass photographic plates about as relevant as those of an old telegrapher.

Obsolescent or not, Sandage isn't about to quit the great cosmological debate that has obsessed him for more than two decades. Though he's sure he'll ultimately win, he isn't sure he'll be around to savor the victory.

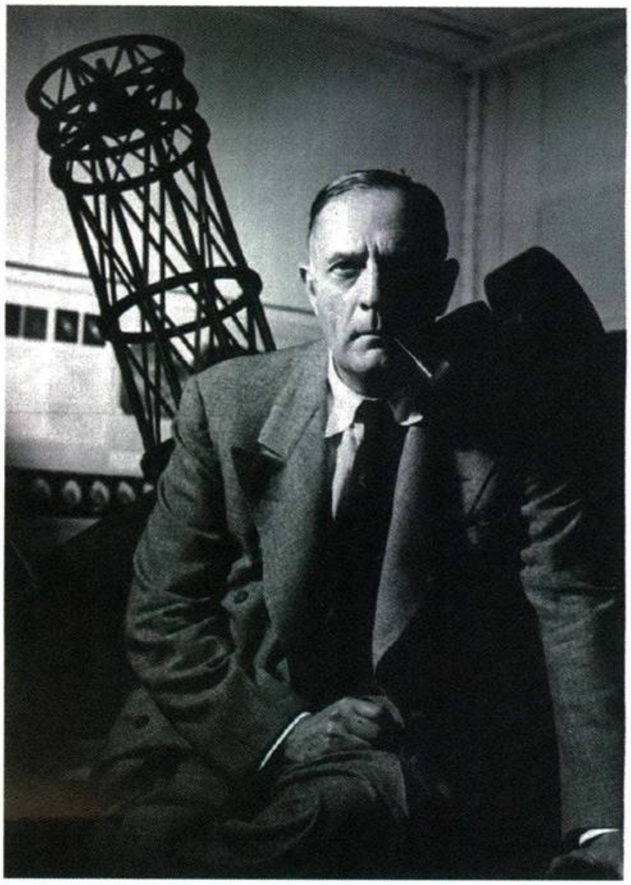
Paradoxically, the Hubble Wars had their origins in one of the great triumphs of 20th-century astronomy. In 1929, after months of painstaking observation with the Mount Wilson Observatory's 100-inch mirror — then the world's premier telescope — Hubble made a momentous announcement: The spectral lines in the light from most galaxies were "stretched" toward the red end of the spectrum. This meant that if the redshifts were interpreted as Doppler shifts — that is, a distortion caused by the light source's movement away from us — the universe was expanding. Moreover, the farther out he looked, the greater the redshifts turned out to be.

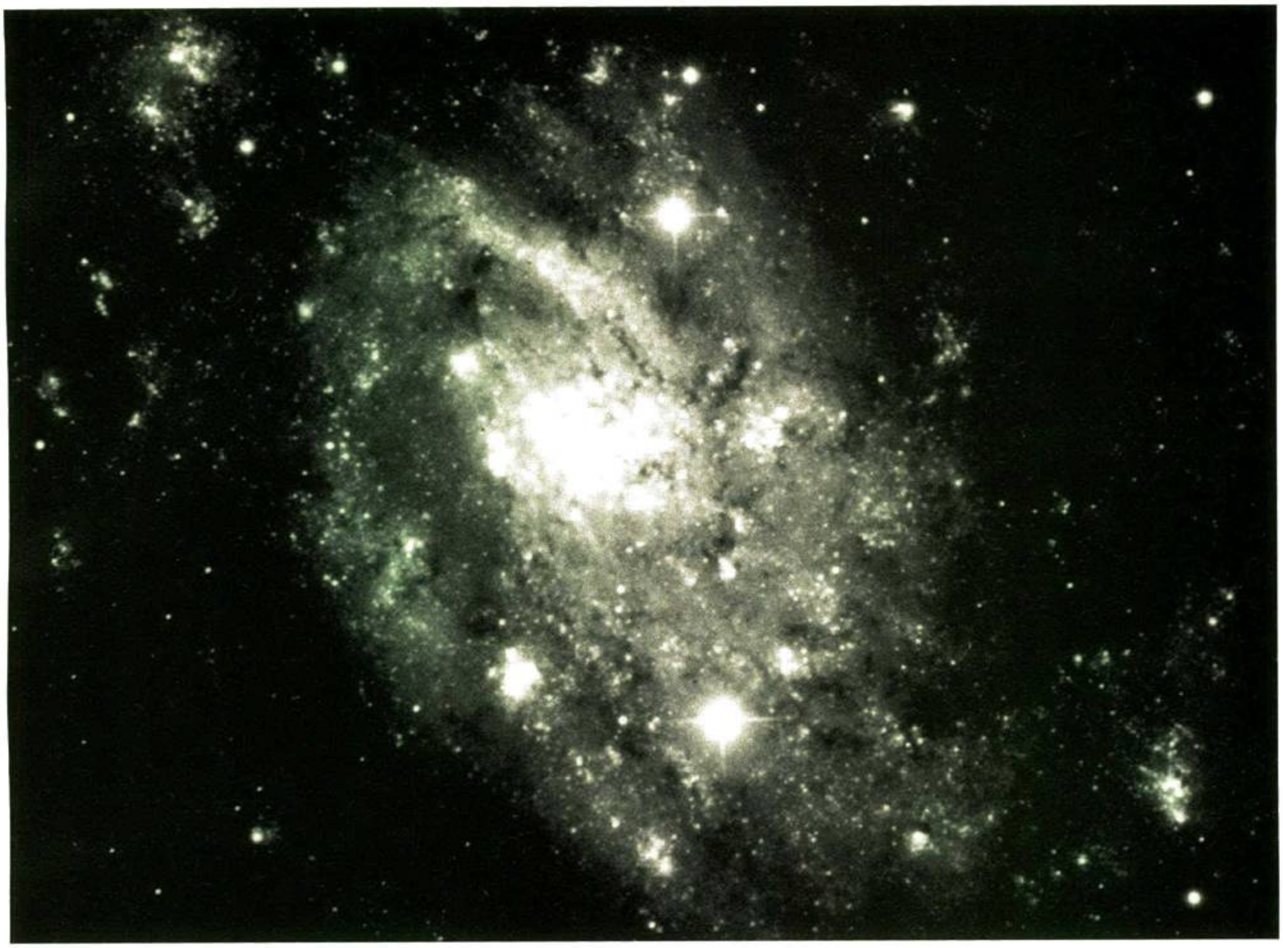
Converting the redshifts to velocities, Hubble saw a direct mathematical kinship: The more distant the galaxies, the faster they were receding from us (and presumably one another). This became known as Hubble's law — though, as Sandage points out, Hubble himself always hesitated to draw any big conclusions. "If you look at his papers, you'll see that he left the question open [about whether the universe is expanding] and maintained that position for the rest of his life."

By itself, Hubble's law isn't proof of anything. Other effects can cause redshifts as well. But even while Hubble was scanning the skies, European theorists were caught up in another game. Solving the equations of Einstein's general theory of relativity, they realized the equations clearly implied that the universe was either expanding or contracting. They thus quickly seized upon Hubble's findings as physical proof of their cosmological musings.

Still, there was a serious flaw in the emerging picture of the cosmos. Hubble's rate of expansion was derived

Sandage's mentor was no one less than the great Edwin P. Hubble, who, whether he admitted it or not, discovered the expansion of the universe back in 1929. Carnegie Observatories





NGC 2403 was the first galaxy outside the Local Group in which Cepheid variables were identified. Sandage and Tammann have used this galaxy as a rung in their cosmological distance ladder. Their research yields a Hubble constant of 55. Most astronomers obtain a higher Hubble constant. Mount Wilson and Palomar Observatories

from a ratio called the Hubble constant (H_0 — pronounced "H naught"), which is easily calculated by dividing the distance of the galaxies by their velocities, measured in kilometers per second per megaparsec (one megaparsec equals 3.26 million light-years). By Hubble's reckoning, if the universe was expanding, it was only two billion years old. In contrast, as geologists knew from other evidence, the Earth itself was clearly older, to say nothing of the sun and other stars. Thus began the great Hubble Wars over the expansion rate of the universe.

Sandage seemed predestined to join the fray. Born to a business professor at Miami University in Oxford, Ohio, and the daughter of the president of a Mormon school, he knew by age 11 what he wanted to do in life. Looking through a friend's telescope, he recalls, "a firestorm took place in the brain." Then and there he decided to become an astronomer. Aware of his religious feelings, some friends say he wanted answers to basic questions about existence. But Sandage dismisses such speculation. "Science holds an entirely separate fascination for me. At the telescope, I'm a strict reductionist."

Sandage spent two years at Miami, then served two years in the Navy as an electronics specialist at the close of World War II. He finished his undergraduate studies at the University of Illinois, majoring in physics even though he feels he wasn't particularly gifted in it. Perhaps more important, he hung around the school observatories, learning the skills of practical astronomy.

Upon graduation in 1948, he headed west, aware that a magnificent new "big eye" — the 200-inch Hale mirror — was about to scan the heavens from California's Palomar Mountain. Enrolling at Caltech, which then ran the observatory in collaboration with Carnegie, he joined the school's first group of Ph.D. candidates in astronomy. The work was grueling, and Sandage is still rankled by the D he got in Richard Feynman's quantum mechanics course. But even before he got his degree, he was spending hours at Mount Wilson collecting data for Walter Baade, his thesis adviser. Then, just as Hubble was beginning his observational program on the 200-inch, the great observer suffered a heart attack and sent word to Caltech astronomy chairman Jesse Greenstein that he needed a graduate student to serve as his assistant. Sandage got the nod, but, looking back on that "lucky break," he doesn't necessarily

"At the telescope, I'm a strict reductionist."

"I don't know why I'm even talking to you," Sandage says, even as he goes right on talking.

In 1974, Sandage and Tammann obtained a distance of 23 million light-years to galaxy M101. Recent observations have confirmed their measurement. Kitt Peak National Observatory

see it as a compliment. Considering the long-standing enmity between the two men, he says, a little too modestly, "I've always wondered who Greenstein would have sent if they really liked each other."

Sandage did a brief postdoc at Princeton with another scientific eminence, Martin Schwarzschild, calculating how stars move off the main sequence — essential to dating them. Then in 1952, it was back to Pasadena as a full-time Carnegie staffer. The old arguments about the age and size of the universe were as hot as ever.

Hubble's original findings had undergone a number of corrections, most notably by Baade. He had spotted a critical flaw in Hubble's analysis. To estimate the distances of M31 and other nearby galaxies, Hubble and his co-workers had used as their "standard candles" variable stars known as Cepheids, whose luminosities (as Henrietta Leavitt discovered back in 1908) are directly correlated to their periods. Baade more accurately calibrated the intrinsic luminosity of Cepheids. After only a few cranks of those clumsy old mechanical calculators that Sandage fondly recalls using, H_0 dropped to 250 km/s/Mpc, down from Hubble's 1929 figure of 500 km/s/Mpc. The universe had doubled in age and size.

In 1953, following Hubble's death, Sandage took up the great galactic distance chase himself — and began making still further downward revisions. Discovering that Hubble's measuring rods in distant galaxies were not stars but highly luminous gas clouds, he dropped H_0 to 180 km/s/Mpc, then to 75 km/s/Mpc. That increased the presumptive age of the universe to some 13 billion years.

By 1963 Sandage was working with a young Swiss astronomer named Gustav Tammann, who would become his lifelong partner even after he returned to Basel. Their goal was to construct nothing less than a colossal cosmological distance ladder. They would use the data that Sandage was gathering at the 200-inch telescope to probe deeper and deeper into the universe in a series of carefully plotted steps.

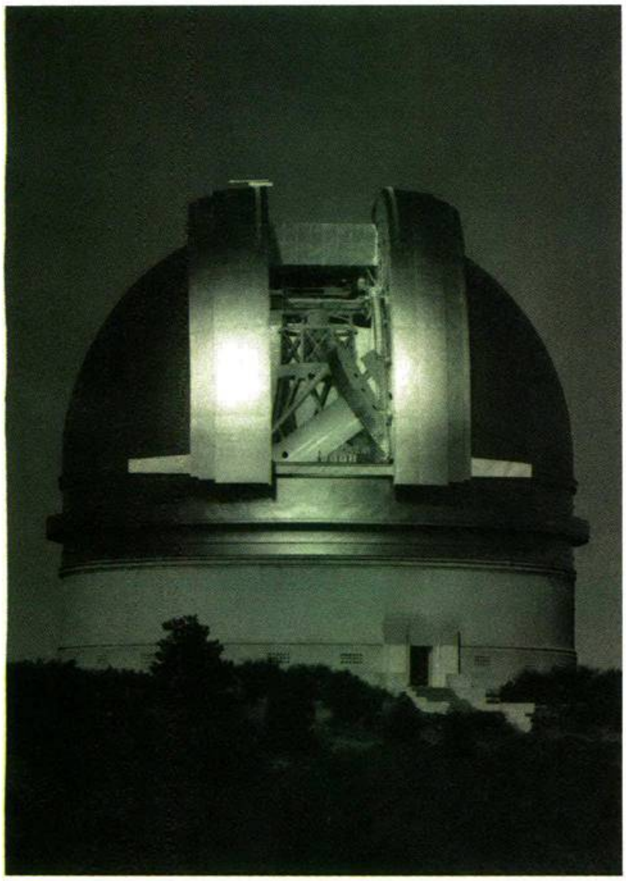
First, they estimated distances to nearby galaxies in the Local Group, then to NGC 2403, a great spiral in the M81 group of galaxies, using Cepheids for both steps. Then, with the distances of these galaxies in hand, they calibrated the luminosity and size of great clouds of ionized hydrogen gas within them. Knowing that these measurements were linked to the overall luminosity of the galaxies, they went on to apply that relationship to determining the distances of even more remote galaxies with similar gaseous regions. Lastly, they turned to a new classification scheme for spiral galaxies developed by Canadian astronomer Sidney van den Bergh, who showed that their luminosity could be estimated from the clarity and contrast of their spiral arms. So, they used this relationship as still another standard candle to gauge the distances of more remote galaxies. In 1975, a dozen years after they began building their ladder, they announced their results: H_0 was 55 km/s/Mpc, plus or minus about

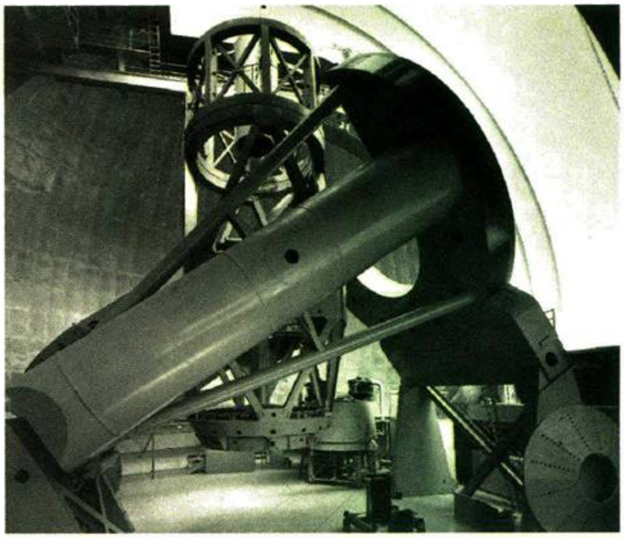
10 percent, which meant the universe might be as old as 18 billion years.

Cosmologists breathed a sigh of relief. The new figures finally reconciled the age of the universe with one of its major components, the ancient groups of stars known as globular clusters, located in the halos of galaxies, which were then believed to be about 18 billion years old. (Their ages have since been reduced to about 15 billion years.) But other astronomers balked at accepting Sandage and Tammann's new H_0, challenging, among other things, their distances to NGC 2403 and the Virgo Cluster and coming up with H_0 values that were as much as twice as large. The French astronomer Gérard de Vaucouleurs, who had taken up residence at the University of Texas, was an especially persistent critic, questioning almost every aspect of the Sandage-Tammann effort. He would continue battling them until his death in 1995. "Very unfortunate, very unfortunate," Sandage says of de Vaucouleurs's death. "Anybody in the middle of a crisis should live to see the resolution of the crisis."

Sandage and Tammann fought back. They relied on a variety of new measuring tools, including white dwarf explosions known as Type Ia supernovae and the so-called Tully-Fisher method, which correlates the rotational velocities of spiral galaxies with their absolute brightnesses. More recently, they joined with other astronomers in using the Hubble Space Telescope to get more precise data on Type Ia supernovae. But their H_0 values have remained around 55. "Our critics say, 'Well, Tammann and Sandage get 55 no matter what the data are,'" Sandage complains. "I say we get 55 because that's the answer."

This is a place familiar to Sandage, the dome for the 200-inch Hale Telescope on Palomar Mountain. Hale Observatories





In his quest to determine the universe's expansion rate, Sandage has frequently turned to the great 200-inch Hale Telescope at the summit of Palomar Mountain in California. This was the world's largest telescope for five decades. Hale Observatories

In paper after paper, Sandage and Tammann tried to show where these critics have committed what they call "observational selection bias" — for example, picking stars and galaxies that are far too bright to serve as standard candles. "But they've ignored us," Sandage complains. "Their eyes glaze over, simply glaze over. Nobody believes my science."

Sandage is ambivalent about retirement. When I ask him what he'll do, he quips, "I'll stay home and read novels." But then he insists life won't change for him. He'll still keep coming to the office and continue to write papers, at a rate of eight or so a year, as well as a history of Mount Wilson astronomy.

Indeed, for Sandage, the attraction of stargazing remains as powerful as ever, as becomes evident during our tour of Mount Wilson, recently reopened to big-league astronomy by the Mount Wilson Institute. Clamoring over the ancient 100-inch Hooker Telescope, he reminisces about the grand days of observing before CCDs and climatized control rooms — about the lonely isolation of these mountaintop eyries, about donning aviation jump suits against the chill, about peering out into the star-filled night through the slit of the open dome.

During those solitary, all-night vigils, he says, "You had all kinds of time to think. You were by yourself in the prime focus, and that's when you got all your ideas. It was inspirational, like being in a Trappist monastery, which" — he repeats, with a chuckle — "is what I've always wanted to do." ▣

Frederic Golden is a science writer based in Santa Barbara, California. He was formerly science editor of Time, *to which he still contributes. He first met Sandage 25 years ago while writing* Quasars, Pulsars, and Black Holes: A Scientific Detective Story.

THE TRIUMPH OF HIPPARCOS

A near-dud satellite helps solve a cosmic conundrum.

by Amy Adams

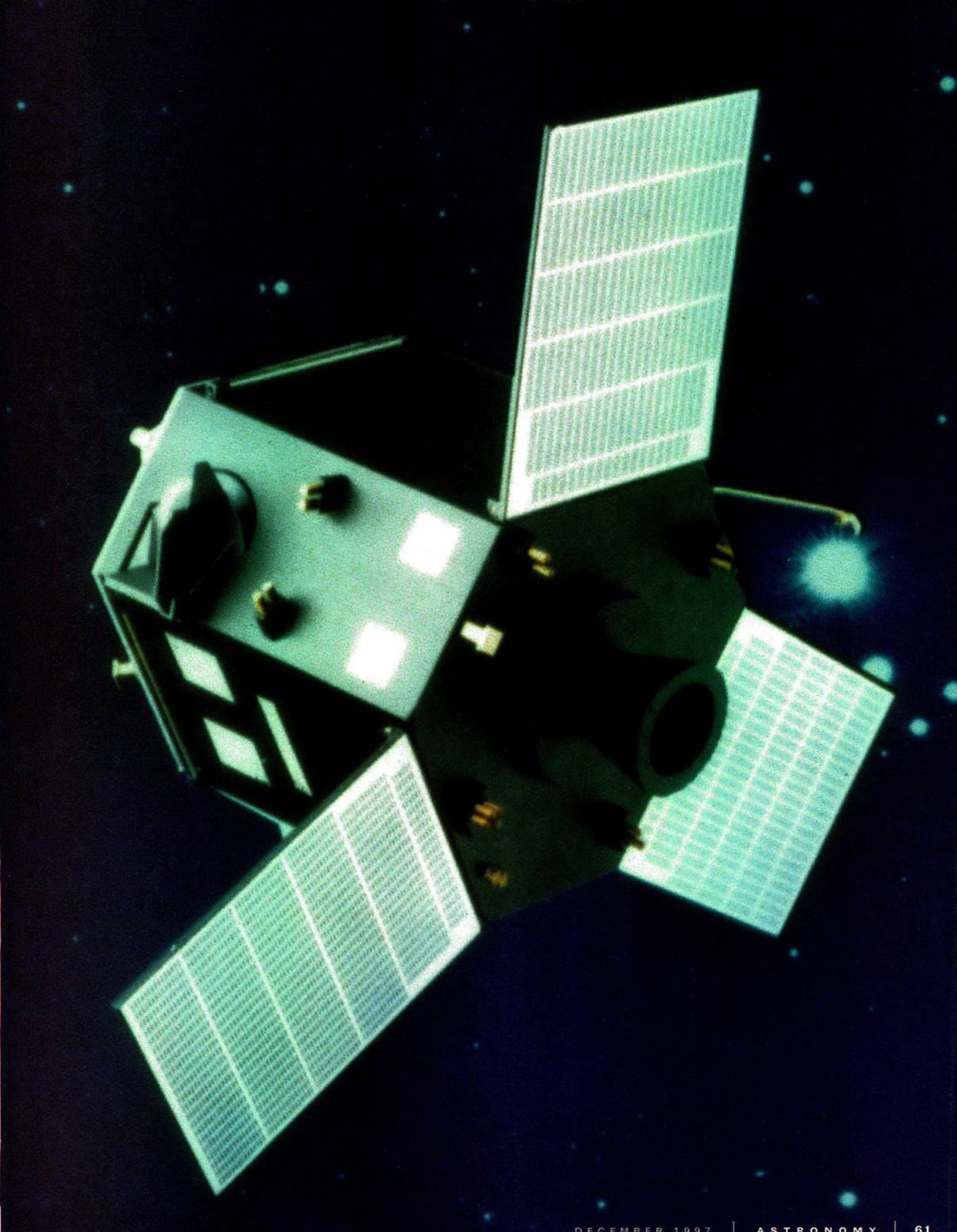
ON AUGUST 8, 1989, MICHAEL PERRYMAN watched the satellite he had helped nurture since 1980 linger in what was supposed to be a transitory orbit. After a perfect launch, an onboard motor failed to fire, and the Hipparcos satellite never reached its intended geostationary orbit. Instead, the satellite remained on a highly elliptical path, one that took it from as far as 22,000 miles above Earth to within 310 miles of the surface over the course of its 10.7-hour orbit around the planet. As Hipparcos crossed Earth's radiation belts twice each orbit, its solar panels took a beating from energetic particles. Despite this inauspicious beginning, when Hipparcos fell silent four years later, the satellite had returned 1,000 gigabytes of data, some of which just might resolve one of astronomy's most illogical discrepancies — that the universe appears to be younger than its oldest stars.

Back in 1967, when astronomers in Europe first dreamed up Hipparcos — an acronym for High-Precision Parallax Collecting Satellite — they hoped it would carry on the legacy of Hipparchus, the ancient Greek astronomer who compiled the first catalog of stars. The satellite was first developed and built by the European Space Agency (ESA). Their goal was to measure the location and movements of more than 120,000 nearby stars with unprecedented accuracy, using Hipparcos's 11-inch mirror, which could look in two directions at once and compare the motions of stars in different parts of the sky. The new, more precise three-dimensional picture of the galactic neighborhood generated by Hipparcos, they hoped, would lead to a better understanding of the nature and evolution of stars.

Hipparcos promised to generate more accurate distances than ever before. Astronomers use the amount stars shift in relation to each other as the Earth goes around the sun — called parallax — to judge how far away a star lies. For example, if you hold your finger an inch in front of your nose and wink, first with one eye and then the other, your finger hops back and forth compared to objects behind it. Move your finger to arm's length, and your finger jumps far less. Still blinking, a nearby fence post moves very little in relation to a distant mountain, but more than a tree that's somewhat farther away. If you felt like calculating the distance to your neighbor's tree, you could measure the distance between your eyes and how much the tree seems to move in relation to the horizon, do some trigonometry, and voilà, you would have your answer.

Though measuring this distance could more easily be done with measuring tape, measuring the

European Space Agency



distances to stars can't. Instead, astronomers take a picture of a star and then take an identical picture six months later when Earth is on the other side of its orbit. The width of Earth's orbit — some 186 million miles across — plays the same role as the distance between your eyes. Stars that shift quite a bit between the two measurements are closer than those that don't. The problem with this technique is that pictures from Earth are blurred by the atmosphere, so it's hard to get accurate measurements. Perryman, ESA's project scientist for Hipparcos, explains that trying to calculate distances from Earth is like trying to accurately measure the distance between the sink and your toothbrush when looking through the frosted glass of the shower. Hipparcos circles Earth outside the atmosphere, so its pictures aren't blurred by the atmosphere's haze.

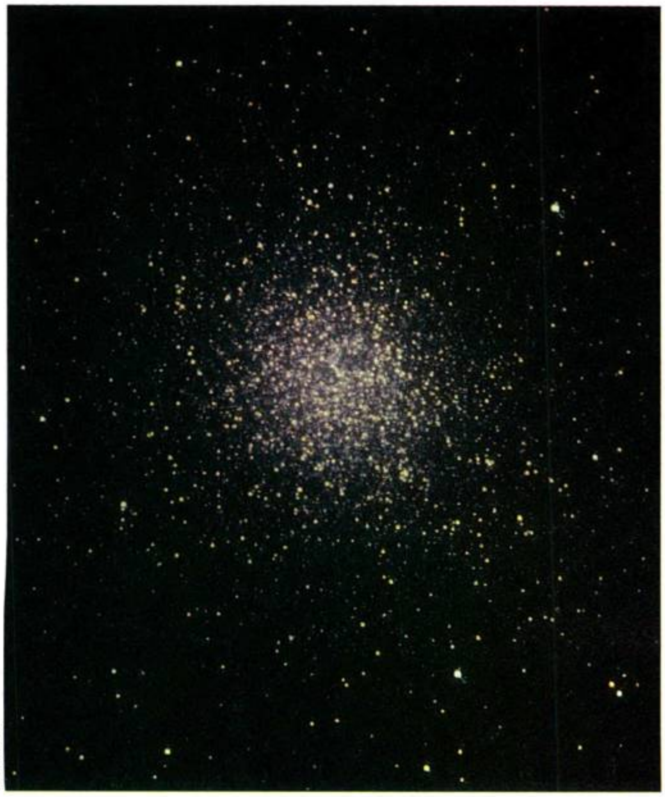
In the beginning, the hopes for Hipparcos were to simply reach a better understanding of stars. Scientists weren't trying to resolve a cosmic age paradox because in 1967 there was none to resolve. Even in 1980 when Perryman got the project underway, the contradiction in ages lay several years ahead.

The paradox came to the forefront in the early 1990s with the introduction of Earth-based distance measurements of pulsating stars known as Cepheids — distant lights that vary in brightness with the regularity of a beating heart — in faraway galaxies. In 1908, Henrietta Leavitt discovered that the period of a Cepheid is directly related to its intrinsic brightness: the brighter the star, the longer the period. Astronomers had observed that brighter Cepheids pulsate slowly over several months, while fainter ones waver at the near-frenetic pace of a few days. If they wanted to measure the distance to another galaxy, they would look for a Cepheid in that galaxy and measure its period. From that period, they could infer its true brightness; by comparing that intrinsic brightness with its apparent brightness as seen from Earth, they would get the distance. These Earth-based distance measurements placed the age of the universe somewhere between eight and 12 billion years.

SEE A CEPHEID FOR YOURSELF

Most of the Cepheids Hipparcos uses to produce data on the distance scale of the universe are extremely remote and, consequently, very faint. But two bright Cepheids are well-placed for Northern Hemisphere observers at some time during most nights of the year. Polaris (Alpha [α] Ursae Minoris), the North Star, varies between magnitudes 1.9 and 2.1 over a period of 3.97 days. The prototypical Cepheid variable, Delta (δ) Cephei, varies between magnitudes 3.5 and 4.4 over a 5.37-day period. Follow the brightness changes of each star with binoculars or a telescope. — Dave Eicher

Omega (ω) Centauri is a globular cluster containing subdwarf stars like those used by Hipparcos to calculate distance measurements.



Franz Kufer

The challenge was to pin down the brightness-period relationship in the first place, which requires measuring the distance to nearby Cepheids by some other method. Hubble, like Hipparcos, escapes the blurring effects of Earth's atmosphere. For this reason, it's an ideal instrument to identify individual Cepheids in distant galaxies — just what Wendy Freedman of Carnegie Observatories in Pasadena, California, and a large international team of astronomers began doing about five years ago. They've taken on the Herculean task of measuring distances to remote galaxies as accurately as possible and using those distances to estimate how fast the universe is expanding. Once they know the cosmic expansion rate, they can calculate how much time has elapsed since the Big Bang, and subsequently determine the age of the universe. Using the Cepheids observed by Hubble, Freedman and colleagues inferred the age of the universe to be about ten billion years — give or take a couple of billion years.

But their preliminary result is in direct conflict with that of groups of scientists at the University of Victoria and Yale. They estimated the age of the oldest stars to be roughly 15 billion years. They based their calculations on a group of stars called subdwarfs, which include our own sun. Subdwarfs live out their lives in a fairly predictable manner, burning hydrogen fuel until they run out of it and then expanding into bloated red giants. They knew that more massive stars burn bright but die early, like galactic gas guzzlers, while smaller stars live out a more frugal — and longer lasting — existence. More massive, hotter stars also tend to be bluer in color than their smaller siblings, so observing a star's color helps determine a star's mass and its life expectancy.

Using this correlation, they worked out the mass and life span of subdwarf stars inhabiting globular clusters, dense knots of stars in the galactic halo that happen to be among the galaxy's oldest tenants. The scientists found that in the oldest clusters, all stars with an expected life span of 14 billion years or so had evolved into red giants, while those expected to survive 15 billion years or longer are still alive. This meant that the stars making up globular clusters were born between 14 and 15 billion years ago — five billion years before the universe itself came into being according to Freedman's estimate. And that was where things stood until

February 1997 when Michael Feast, then director of the South African Astronomical Observatory, announced his results from the Hipparcos data.

Feast and his colleague Robin Catchpole of the Royal Greenwich Observatory requested Hipparcos distances to a group of Cepheids in our own galaxy back in 1982. At that time, they hoped the more accurate Hipparcos measurements would refine the Cepheid distance scale. Because Hubble is used for so many important projects, it can't be devoted exclusively to doing position measurements. Limited data, like that gathered by limited Hubble use, can lead to large errors — errors that Hipparcos could eliminate. By 1997, Feast suggested that the refined scale might also resolve the apparent age discrepancy. And resolve it did, he thinks.

The Hipparcos distances pushed the Cepheids ten percent farther away than astronomers had previously thought, inflating the universe and aging it by a similar ten percent. Moving the stars farther away meant they must be intrinsically brighter (and, hence more massive) to appear as dim as they do on Earth, and more massive stars mean a shorter life span. By making the universe older and the stars younger, the two now appear to fall within the same age range — give or take a couple of billion years. Feast announced both ages to be roughly 11 to 12 billion years, clearing up one of astronomy's biggest headaches.

The Hipparcos data came from over three years of constant data collection. While orbiting Earth, Hipparcos swiveled in a circular motion every two hours, taking a swath of pictures 1° wide covering a 360° loop, each loop containing roughly 2,000 stars. It then turned slightly and took another circle of pictures, and another, until it had photographed the entire sky thousands of times over. Earth-based scientists then pieced together the many pictures to create a complete spherical map of the sky. By comparing these maps at different times during the Hipparcos mission, researchers could measure each star's parallax and from that calculate its distance.

The Hipparcos data generated a 3-D map of the stars with their positions pinned down to within one milliarcsecond of accuracy: equivalent to the size of a golf ball viewed from across the Atlantic. "I was told many times that it would not work," says Perryman. "I think it is very easy to look at a big idea and be skeptical. You aren't prepared if your intuition doesn't permit it." But it did work, and Perryman is thrilled.

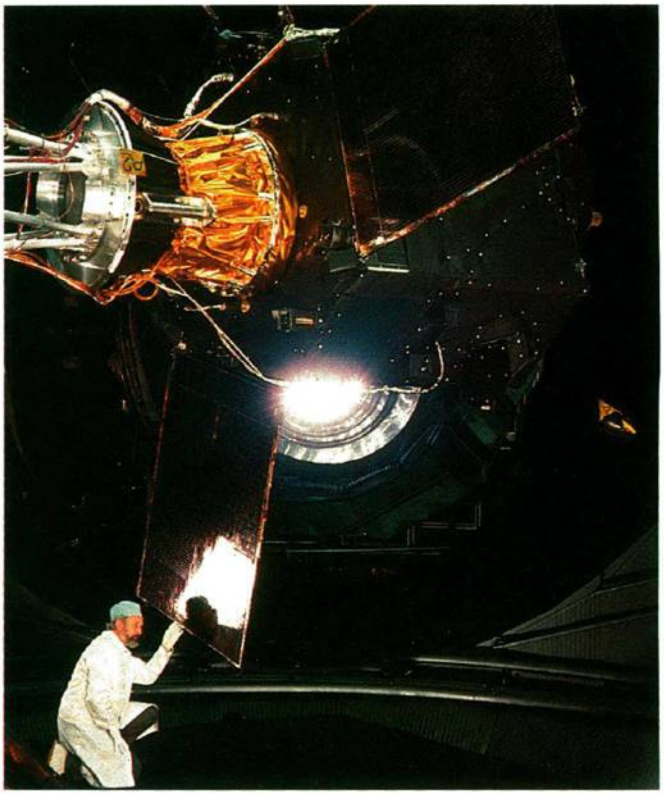
Perryman and Catherine Turon, leader of the Input Catalog Consortium for Hipparcos and an astronomer at the Observatoire de Paris-Meudon in France, both feel confident that the Hipparcos numbers are accurate. "I was very concerned just after the launch," says Turon, who has been part of the project since 1974, "but now it is very exciting. With such data we can make excellent science."

Hipparcos operated for more than a year longer than expected — despite high radiation levels in the altered orbit — and generated more accurate data and more of it than the team had anticipated. That Hipparcos wasn't expected to function at all makes these results all the more exciting, says Perryman. "Initially, and for the first few weeks, it was assumed that the mission would be an almost total failure." He adds, "The hope was really that we would be able to make enough measurements to validate the principles of the satellite, but it was not expected that we would be able to acquire enough data — over a long enough period of time — to construct a useful star catalog." But they did, and in January 1997 ESA released the Hipparcos data to astronomers who had been kept waiting for 17 years. Those who had submitted proposals back in the early 1980s had exclusive rights to the data until June 1997 when ESA made the entire 16-volume data set public.

Feast's resolution to the age conflict, however, didn't convince all the skeptics. Many remained skeptical, thinking that the Cepheid data couldn't stand alone. But other studies using Hipparcos data to measure distances to subdwarf stars in globular clusters suggest that scientists may be moving toward consensus. Neil Reid, an astronomer at the California Institute of Technology, has come up with results that shift the subdwarfs, putting them about ten percent father away than previous estimates — matching Feast's Cepheid results.

Although another study conducted by Turon and Frederic Pont of the Geneva Observatory provided results that give an older age for the subdwarfs (roughly 14 to 16 billion years old), Catchpole says that differences of a few billion years between the various group's data are nothing to fret over. "We're talking 10 to 20 percent. I think that's quite an achievement. It's very exciting that different lines of action all lead to the same ages." Catchpole is willing to wager, for now, that the age of the stars and the universe falls between 12 and 16 billion years — a range that will narrow when more astronomers have a look at the Hipparcos data. "The headache might come back," Reid agrees, "but it won't be as bad as it was."

Amy Adams is a freelance writer based in Santa Cruz, California. She admires stars but measures with rulers.



A full-sized model was created for rigorous qualification testing before Hipparcos was built in order to ensure precision and accuracy.

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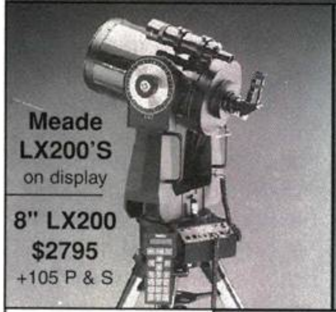

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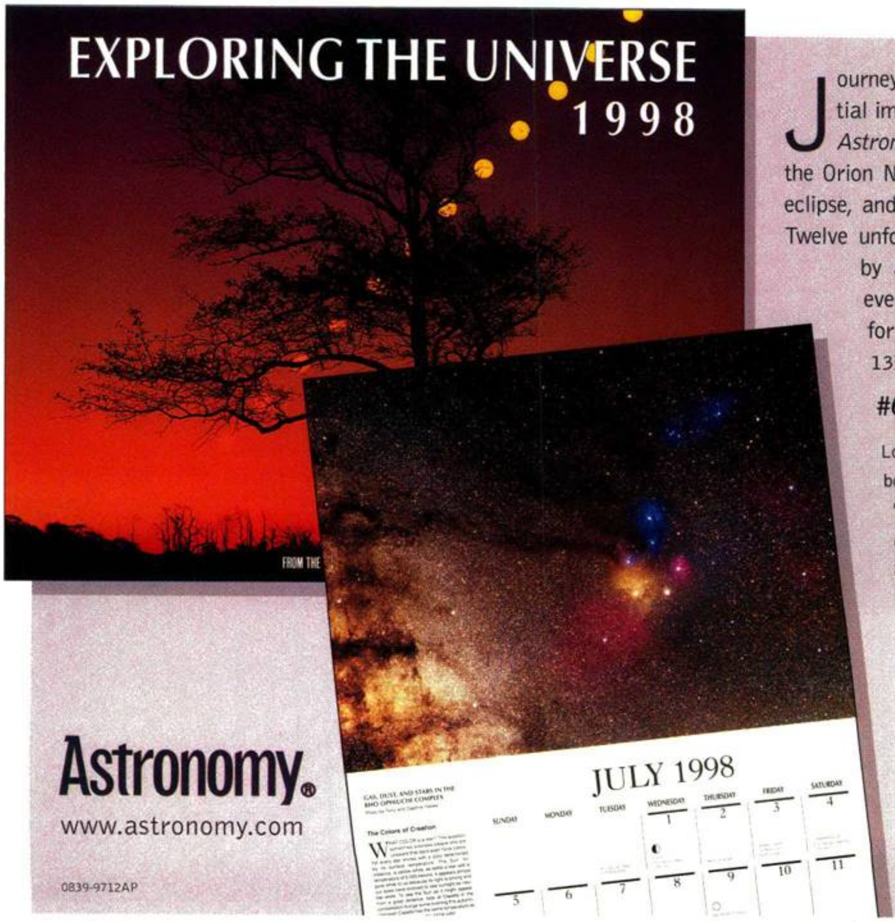

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THE SKY SHOW

The cold evenings of December offer up a smorgasbord of planetary delights, including a pretty cover-up of the Ringed Planet by a gibbous moon. By Martin Ratcliffe and Rick Shaffer

▶ Six planets congregate in the December evening skies. While Mercury and Venus prepare to move between Earth and the sun, on the far side of the solar system, Mars, Jupiter, Uranus, and Neptune appear to lie in the same direction, toward the constellations of Sagittarius and Capricornus. Each planet makes its way in a slow procession against the background stars, and as they do, a number of interesting conjunctions occur.

First to become noticeable as twilight falls, **Venus** and **Jupiter** are the most brilliant points of light in the sky. Venus is at its greatest altitude for Northern Hemisphere observers early in the month, standing 25° high at sunset. Like a lightning bug in summer, it seems to hug the horizon. But unlike the lightning bug, the reflected sunlight from Venus is constant, reaching maximum brightness at magnitude –4.7 on the 11th. Telescopic viewers will be able to watch a beautiful, ever-shrinking crescent through the month as Venus approaches superior conjunction, scheduled to occur in January.

From night to night during December, **Mars** plays tag with Venus. A crescent moon joins the fray briefly too, passing to the north of Venus on December 3. Leading the way before they meet, Venus passes 2.5° south-southeast of **Neptune** on December 9. Mars follows suit a week later, passing 1.6° south-southeast of Neptune. By December 22, Venus is slowing its eastward nightly moves and lies 1.1° north of Mars. What a stunning sight this pair reveals through a rich-field telescope. Mars shines dimly at magnitude 1.2, making the difference in brightness between the two almost six magnitudes. Venus turns around on Christmas Day and begins heading west toward the sun's glow, setting two hours after the sun.

As Venus starts to move westward, Mars continues its easterly track, bringing it 0.6° from **Uranus** on the night of December 26. Uranus is a dim 6th magnitude, and though you can see it in binoculars, low power on a telescope should place it within the same field of view as Mars. Remember as you look at the two planets that they are not really near each other. Mars lies 192 million miles from Earth, and Uranus is exactly ten times farther away, at 1.9 billion miles distant. Also notice that Mars's apparent diameter of 4.4" is not much more than Uranus's apparent size of 3.4". Since it is much

Winter is back, and the bright constellations of Taurus, Orion, and Canis Major will vie for your attention with December's bright planets. Here the winter constellations come up over Mudstone Cliff in Anza-Borrego Desert State Park in California.

Jerry Schad

DECEMBER 1997

2 Asteroid Dembowska is at opposition, 9 a.m. EST
The moon passes 5° north of Mars, midnight EST

3 The moon passes 7° north of Venus, noon EST

5 The moon passes 3° north of Jupiter, 3 a.m. EST

7 First quarter moon is at 1:09 a.m. EST
Venus passes 3° south of Neptune, 3 p.m. EST

9 The moon passes 0.2° north of Saturn, 2 a.m. EST (page 72)
The moon is at perigee (229,208 miles from Earth), 11:55 a.m. EST
Asteroid Thalia is at opposition, 2 p.m. EST (page 73)

11 Venus is at greatest brilliancy (magnitude –4.7), 6 p.m. EST (page 75)

12 The moon passes 0.5° north of Aldebaran, midnight EST

13 Geminid meteor shower peaks (page 73)
Full moon is at 9:37 p.m. EST

17 Mercury is in inferior conjunction, 3 a.m. EST

19 Asteroid Euterpe is at opposition, 2 a.m. EST (page 73)

21 Winter solstice is at 3:07 p.m. EST (page 71)
Last quarter moon is at 4:43 p.m. EST
The moon is at apogee (251,197 miles from Earth), 6:25 p.m. EST

22 Venus passes 1.1° north of Mars, 6 a.m. EST

25 Venus is stationary, 9 a.m. EST

27 The moon passes 2° north of Mercury, 10 p.m. EST

29 New moon is at 11:56 a.m. EST

31 The moon passes 1.3° north of Venus, 8 a.m. EST
The moon passes 4° north of Mars, 10 p.m. EST

Sun.	Mon.	Tue.	Wed.	Thu.	Fri.	Sat.
	1	2	3	4	5	6
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14	15	16	17	18	19	20
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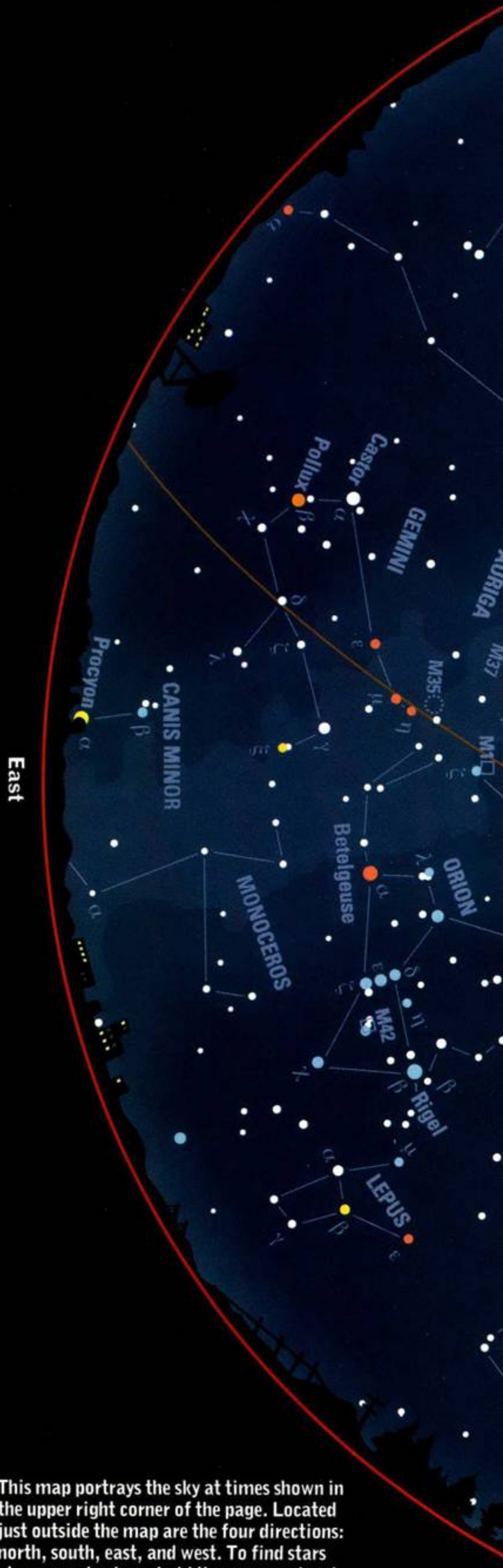
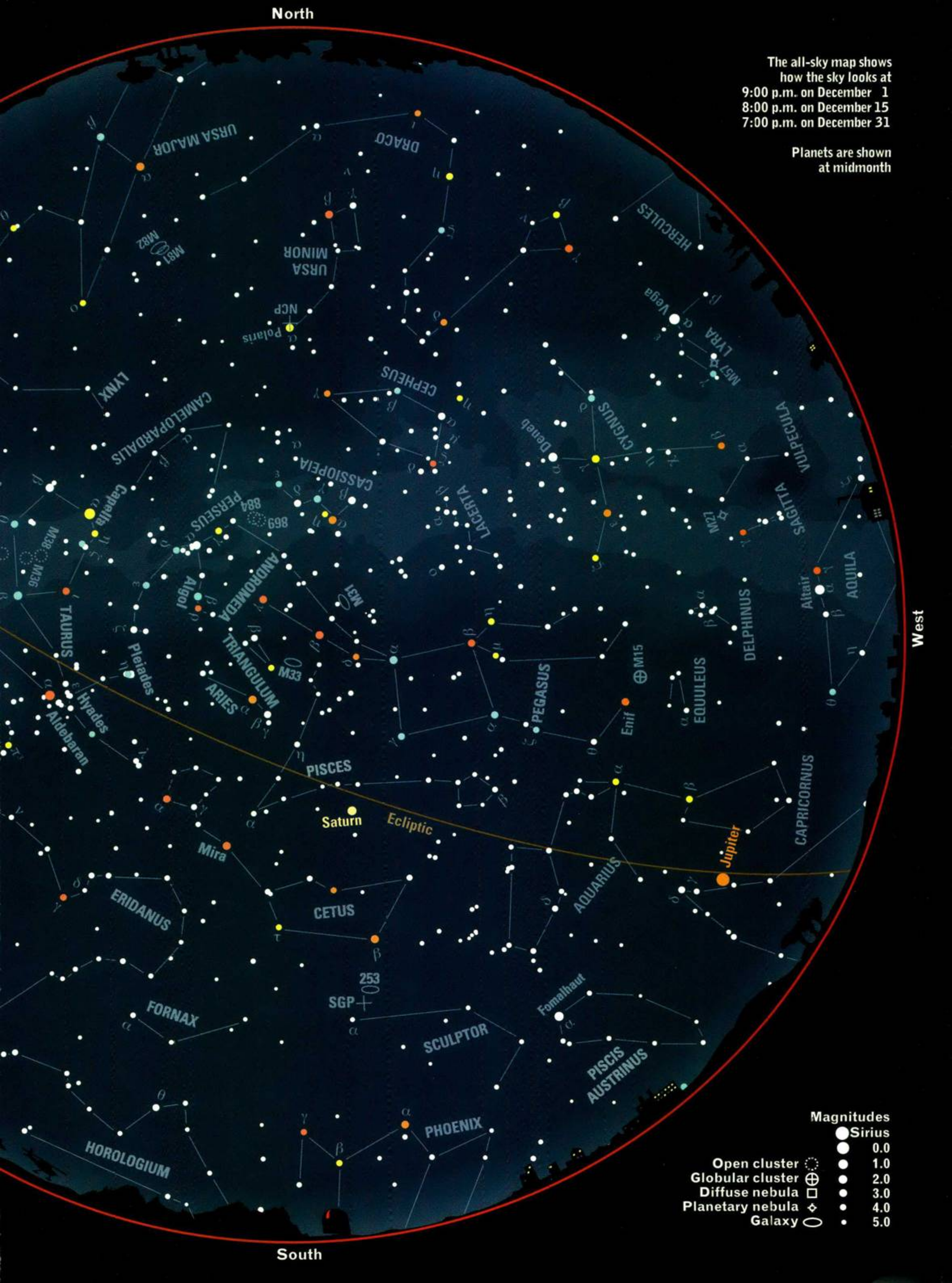


This map portrays the sky at times shown in the upper right corner of the page. Located just outside the map are the four directions: north, south, east, and west. To find stars above your horizon, *hold the map overhead* and orient it so a direction label matches the direction you're facing. The stars above the map's horizon now match what's in the sky.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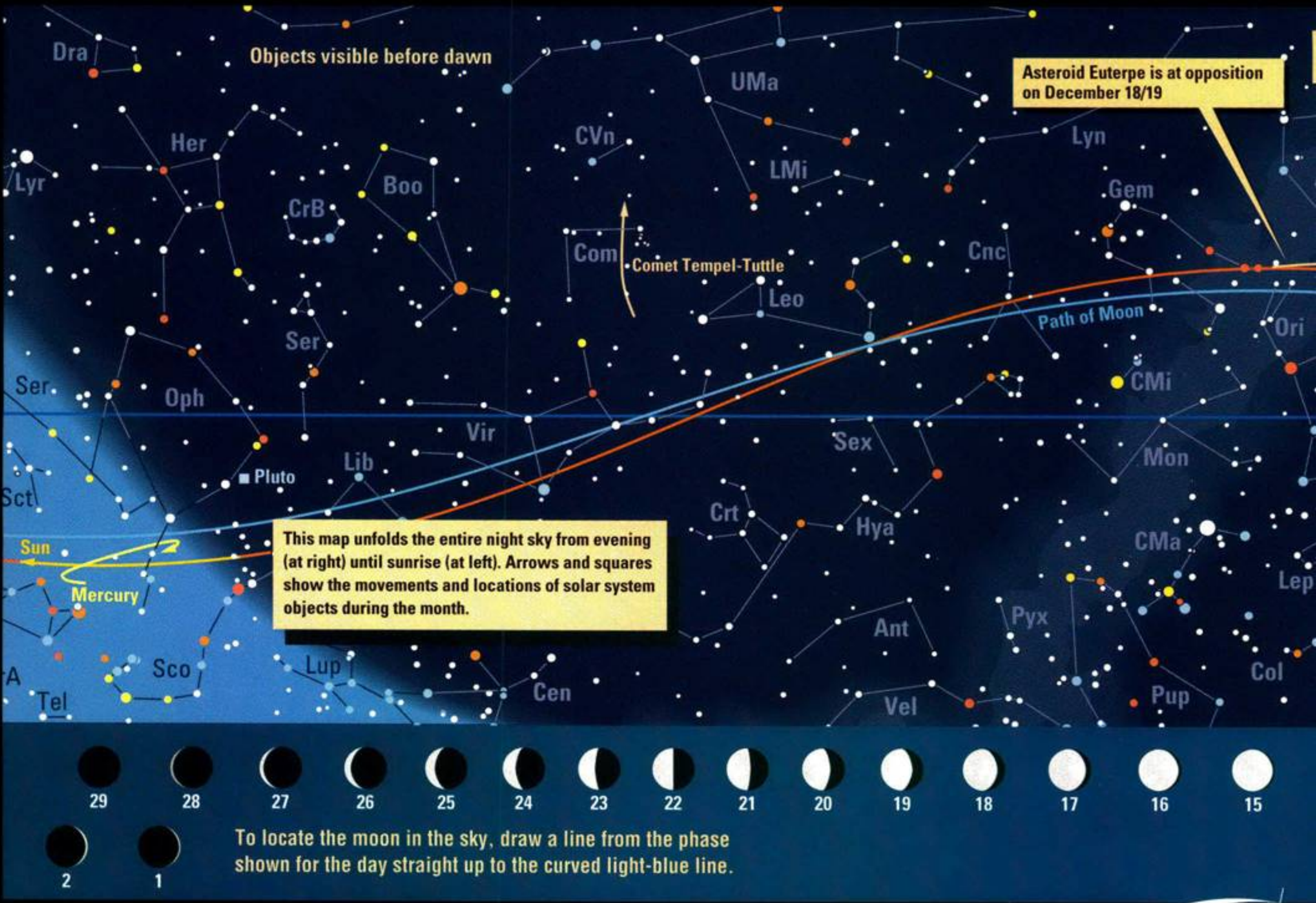
Polaris
Vega
LYRA
M57
LYNX
CEPHEUS
CAMELOPARDALIS
CYGNUS
Deneb
VULPECULA
CASSIOPEIA
Capella
PERSEUS
884
869
LACERTA
M27
SAGITTA
M38
M36
ANDROMEDA
M31
Altair
AQUILA
Algol
TAURUS
Pleiades
TRIANGULUM
M33
DELPHINUS
M15
EQUULEUS
Hyades
Aldebaran
ARIES
PEGASUS
Enif
PISCES
CAPRICORNUS
Saturn
Ecliptic
Mira
AQUARIUS
Jupiter
ERIDANUS
CETUS
253
SGP
FORNAX
SCULPTOR
Fomalhaut
PISCIS AUSTRINUS
HOROLOGIUM
PHOENIX
Magnitudes
Sirius
0.0
1.0
2.0
3.0
4.0
5.0
Open cluster
Globular cluster
Diffuse nebula
Planetary nebula
Galaxy

The all-sky map shows
how the sky looks at
9:00 p.m. on December 1
8:00 p.m. on December 15
7:00 p.m. on December 31

Planets are shown
at midmonth

THE PATH OF THE PLANETS


Objects visible before dawn
Dra
Lyr
Her
CrB
Boo
CVn
UMa
LMi
Lyn
Gem
Com
Leo
Cnc
Ser
Oph
Ser
Vir
Lib
Sex
CMi
Ori
Sct
Pluto
Path of Moon
Mon
Sun
Mercury
Crt
Hya
CMa
Lep
Sco
Lup
Cen
Ant
Pyx
Pup
Col
Tel
A
Vel
29
28
27
26
25
24
23
22
21
20
19
18
17
16
15
2
1

Asteroid Euterpe is at opposition on December 18/19

Comet Tempel-Tuttle

This map unfolds the entire night sky from evening (at right) until sunrise (at left). Arrows and squares show the movements and locations of solar system objects during the month.

To locate the moon in the sky, draw a line from the phase shown for the day straight up to the curved light-blue line.

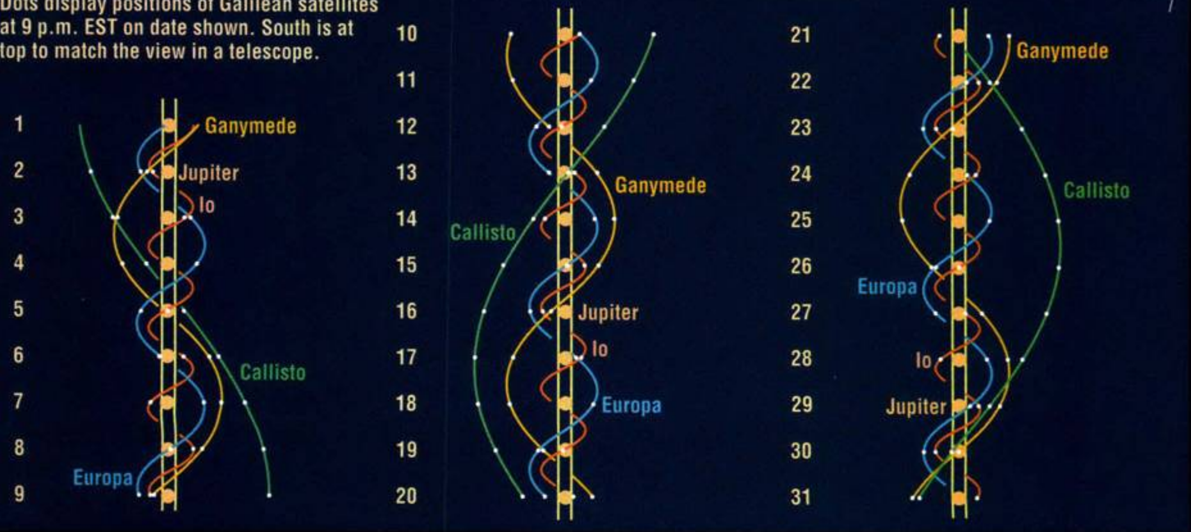
10"

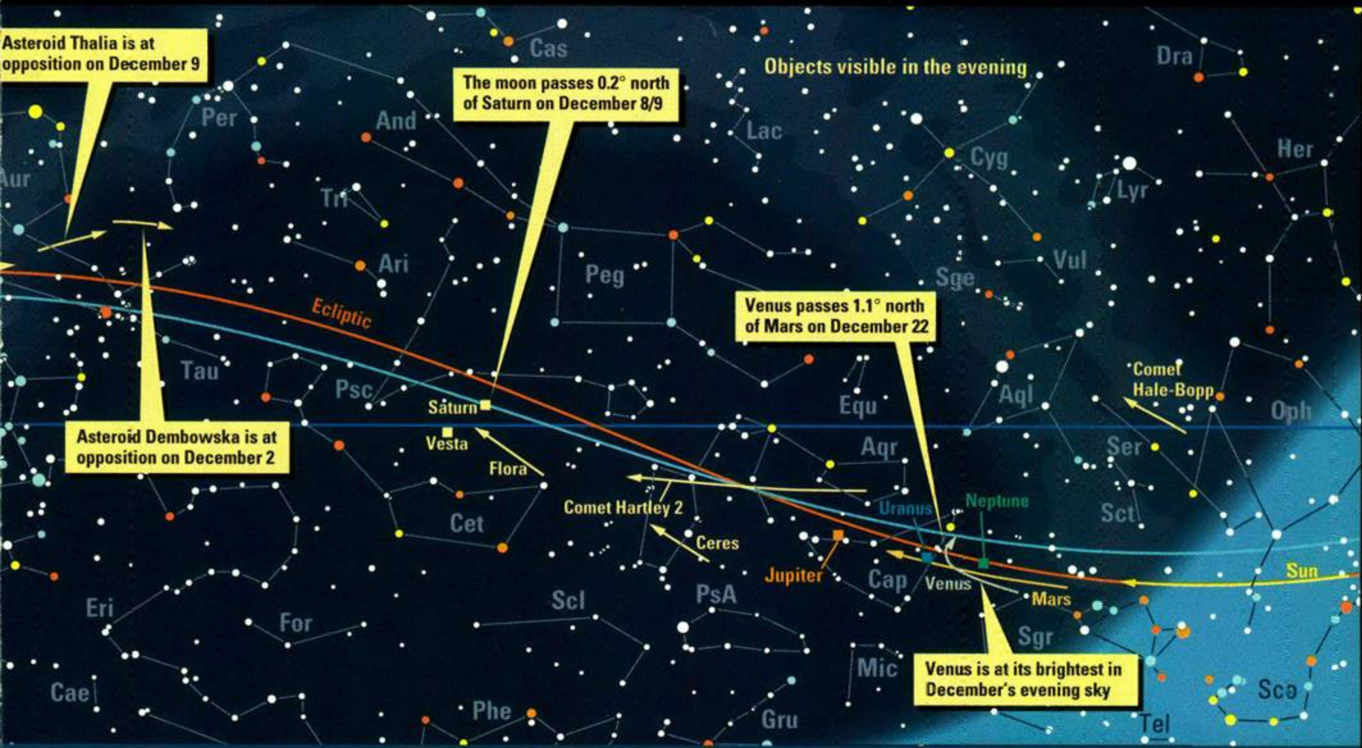
S
W E
N

PLANETS	MERCURY	MERCURY	VENUS	VENUS	MARS
Date	December 1	December 31	December 1	December 31	December 15
Magnitude	−0.3	0.0	−4.6	−4.5	1.2
Angular Size	7.0"	7.7"	34.6"	55.4"	4.5"
Illumination	56%	45%	34%	9%	96%
Distance (AU) from Earth	0.963	0.878	0.482	0.301	2.081
Distance (AU) from Sun	0.364	0.363	0.723	0.720	1.385
Right Ascension (2000.0)	18h00.9m	17h08.7m	19h41.4m	20h22.0m	19h59.2m
Declination (2000.0)	−25°37'	−20°15'	−24°24'	−17°36'	−21°52'

JUPITER'S MOONS

Dots display positions of Galilean satellites at 9 p.m. EST on date shown. South is at top to match the view in a telescope.




Cas
Per
And
Aur
Tri
Ari
Peg
Lac
Cyg
Lyr
Dra
Her
Vul
Sge
Ecliptic
Tau
Psc
Saturn
Vesta
Flora
Equ
Aql
Comet Hale-Bopp
Ser
Oph
Aqr
Cet
Comet Hartley 2
Ceres
Uranus
Neptune
Sct
Jupiter
Cap
Venus
Mars
Sun
Eri
For
Scl
PsA
Sgr
Mic
Cae
Phe
Gru
Tel
Sco

Objects visible in the evening

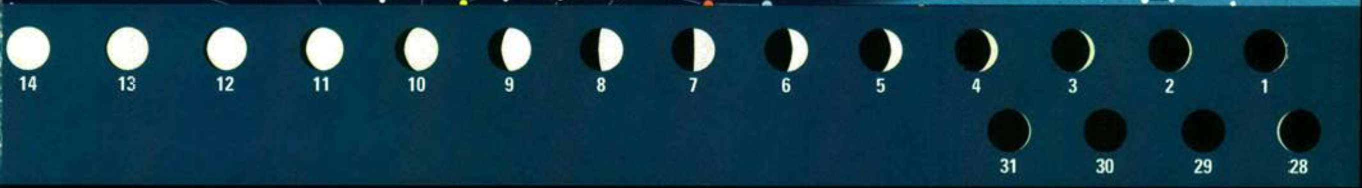
Asteroid Thalia is at opposition on December 9

The moon passes 0.2° north of Saturn on December 8/9

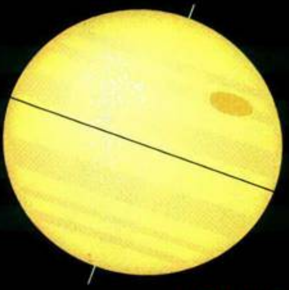
Asteroid Dembowska is at opposition on December 2

Venus passes 1.1° north of Mars on December 22

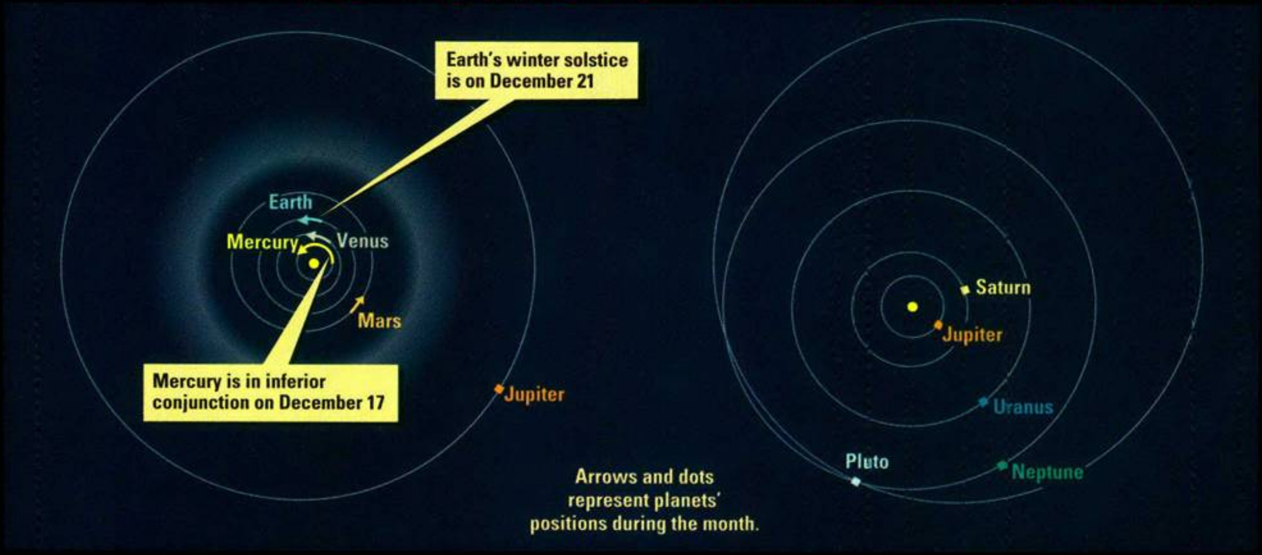
Venus is at its brightest in December's evening sky


14
13
12
11
10
9
8
7
6
5
4
3
2
1
31
30
29
28

JUPITER	**SATURN**	**URANUS**	**NEPTUNE**	**PLUTO**
December 15	December 15	December 15	December 15	December 15
−2.1	0.6	5.9	8.0	13.8
35.8"	18.5"	3.4"	2.2"	0.1"
99%	100%	100%	100%	100%
5.511	8.982	20.548	30.943	30.945
5.026	9.371	19.842	30.146	30.026
21h26.7m	0h53.9m	20h35.4m	20h01.7m	16h25.5m
−15°59'	2°58'	−19°17'	−20°07'	−9°38'



THE PLANETS IN THEIR ORBITS


Earth
Mercury
Venus
Mars
Jupiter
Saturn
Jupiter
Uranus
Pluto
Neptune

Earth's winter solstice is on December 21

Mercury is in inferior conjunction on December 17

Arrows and dots represent planets' positions during the month.

FIRST VIEWS: Old Sol Celebrates the Solstice

At precisely 3:07 p.m. EST on December 21, the sun reaches the farthest point south in its travels around the celestial sphere. Despite the fact that for the southern half of the world it occurs in the middle of summer, this event is known as the winter solstice. That's because most humans lived in the Northern Hemisphere at the time our forebears were noticing such things for the first time. On December 21, those of us who live in the Northern Hemisphere will experience the shortest day of the year. People located in the Southern Hemisphere, on the other hand, will experience their longest day of the year.

You might assume that the 21st also features the latest sunrise and the earliest sunset of the year, but in fact, this isn't true. To understand what's happening, we have to examine a lovely curve known as the analemma.

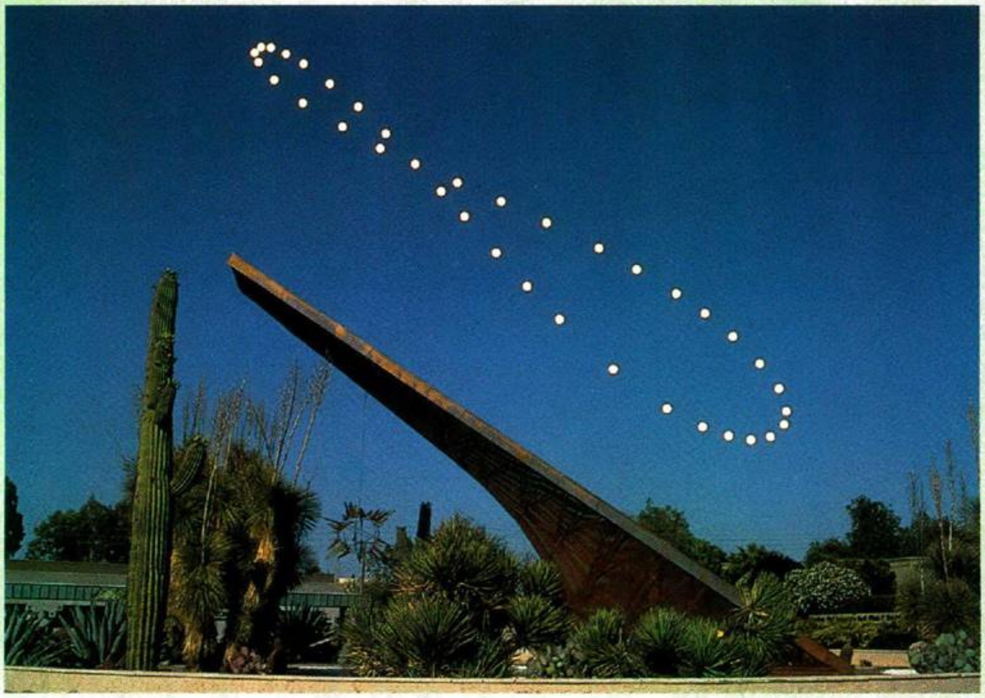
We start with the fact that our method of reckoning time is based on the sun's daily trip across the sky. Specifically, we've regarded mid-way, or "noon," as that time when the sun is highest in the sky, half-way between sunrise and sunset. Of course, the sun appears at a different point in the sky depending on where you live — so noon in Oklahoma City occurs a little bit later in the day than it does in Tulsa.

In fact, each place on Earth has its own apparent solar time, which is behind all those places to the east and ahead of those to the west. Apparent solar time can be regarded as the time given by a simple sundial. (Only when railroad schedules became hopelessly jumbled did the concept of time zones come into effect. Until then, each little hamlet, ville, and burg kept its own time.)

If our planet revolved around the sun in a perfectly circular orbit, its daily motion would be constant, and apparent solar time would be constant. This "if only" time is called mean solar time. It's rate is what governs time here on Earth. For two important reasons, apparent solar time isn't constant. The first reason is that Earth's orbit is not a circle, but rather an ellipse. As Johannes Kepler showed in the 17th century, this means that we travel fastest in our orbit around January 1, when we lie closest to the sun, and slowest around July 4, when we're farthest from the sun.

The tilt of Earth's axis with respect to the plane of its orbit also adds a component to the equation. At times, the apparent sun is faster than the mean sun, and at other times, it lags behind its fictional self.

When these two effects are superimposed, you get the analemma seen below. You can generate the analemma by plotting the position of the sun in your sky at the same time each day, as astrophotographer Frank Zullo did several years ago. Between September 9, 1990, and August 23, 1991, he made 37 exposures of the sun on a single film frame. Each photo was taken at exactly 8:00 a.m. MST. He then used a simple double exposure technique, "burning in" the suns into the sky above the sundial.



Frank Zullo

The analemma graphically shows why the latest sunrise and earliest sunset don't occur on the day of the solstice. If apparent solar time equaled mean solar time, the analemma would be a straight line running from the summer solstice at the upper left of the curve to the winter solstice at lower right. The figure-eight curve shows how far off the two times are from each other. When the sun is above the long axis of the curve, the apparent sun runs ahead of the mean sun; when the sun is below, the apparent sun is behind. Thus the apparent sun, moving clockwise around the loop at lower right, is ahead of the mean sun before the solstice. That causes the apparent sun to set earlier. After the solstice, however, the apparent sun is behind the mean sun, causing the sun to rise later. At a latitude of 40° north, the earliest sunset comes on December 7, while the latest sunrise occurs on January 4.

farther away, this simple observation reveals that Uranus is truly a giant planet (as if you needed assurance). In reality, Uranus is more than seven times larger than nearby Mars. Even so, both planets appear so small to us that little detail can be discerned through any amateur telescope.

Uranus can be found earlier in the month without the guiding influence of Mars. Locate Rho (ρ) Capricorni and the nearby fainter stars of Pi (π) and Omicron (o) Capricorni, which form a small, neat triangle easily seen in binoculars. Observe the distance from Pi to Omicron, extend an imaginary line south of Omicron roughly that distance, and you arrive at the spot where Uranus can be found. Both Mars and Uranus set a little more than two hours after the sun by year's end.

A little closer to home and eight magnitudes brighter than Uranus is Jupiter, shining at magnitude –2.1. The planet's seething atmosphere and dazzling array of four moons are being surveyed by the Galileo spacecraft in stunning detail. For those who want to take a look for themselves, the daily motions of clouds and moons can be tracked even with a small telescope. Jupiter's path takes it eastward in northern Capricornus, ending the year to the north of Nashira, or Gamma (γ) Capricorni. It sets by 8:30 p.m., allowing at least two hours of observation. In addition, a waxing crescent moon passes northwest of Jupiter on December 4.

After the early evening flurry of planetary activity begins to die down, the Milky Way will be evident to dark-site viewers as the

The Moon Grazes the Ringed Planet

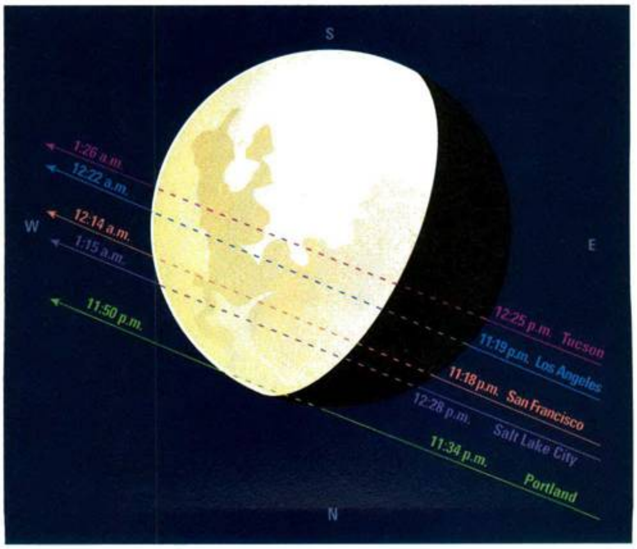
On the night of December 8/9, the moon will occult Saturn for observers west of the Rocky Mountains and south of a line from Portland, Oregon, to Butte, Montana. Along that line, Saturn will appear to graze the northern limb of the moon, a truly spectacular sight. The International Occultation Timing Association (IOTA) will be happy to give you tips on observing this grazing occultation. Just visit their website at http://www.sky.net/~robinson/iotandx.htm.

Kwan Ihn

Adding to the enjoyment is the fact that the dark portion of the gibbous moon will first intercept Saturn. Here's an interesting observation: As the moon occults Saturn, you can see that its appearance is in no way distorted by the presence of the moon's limb. This demonstrates that the moon lacks an atmosphere. As you proudly show your non-astronomer relatives, friends, and neighbors this event, you can wow them with this tidbit. Just remember, the actual occultation occurs fairly quickly, so get the other observers lined up and ready for a quick look.

Saturn's assorted butterscotch and brown hues, contrasted with the sterile gray-green of the moon's disk, are certainly a fabulous sight. To catch Saturn reappearing on the moon's sunlit limb, be sure you're looking at the proper place at the right time.

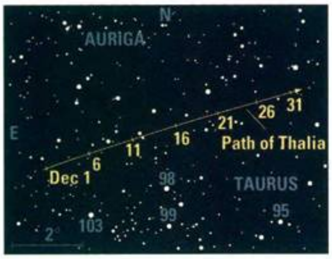
If you intend to image this event, remember a few things: (1) For entry into the occultation, adjust your exposure to Saturn's brightness. Practice imaging Saturn early in the evening before the occultation, as you'll have no time to do so during the occultation. (2) Also practice imaging the sunlit limb of the moon. Adjust your exposure for Saturn's egress so that the strongest pixel count in the moon's image is 95 percent of maximum. This will place Saturn's much dimmer image somewhere in the lower 20 percent of the range. To deal with this disparity of brightness, you can either globally compress the dynamic range of the image of the moon and Saturn (by histogram-squashing), or deal with Saturn's image only, and boost its pixel count by an appropriate amount. Regardless of how you process the image, adjust your exposure to the 95-percent-of-maximum count. This will maximize the signal-to-noise ratio of Saturn's raw image.

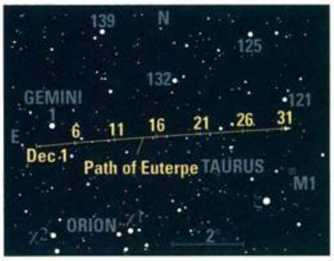


All illustrations by *Astronomy*: Elisabeth Rowan and Terri Metzger

Two Asteroids Are Bullish on Bulls

Two asteroids, 23 Thalia and 27 Euterpe, pass through Taurus the Bull this month. Fortunately, Taurus is high in the sky these December nights, so you'll have a leg up on the bad winter seeing. Remember, though, to let your telescope have at least an hour to cool before you start viewing. Also, be sure not to set up your scope where you'd have to view over a major source of heat. These two asteroids shine at magnitude 9.2 for Thalia and 8.4 for Euterpe, so you'll want to bump up the power after you have clearly identified the field using the maps below.



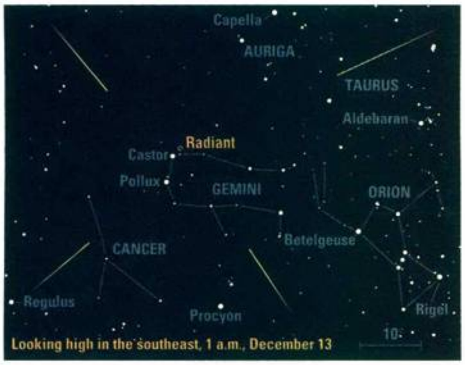


Will You Glimpse a Meteor?

Jerry Schad

Year in and year out, the Geminid meteor shower is the best of the year. They're rivaled only by the Perseids, which have the grace to occur in August, when we only have to deal with mosquitoes and thunderstorms. This year, the Perseids peaked just after first quarter moon, so the moon set before the good viewing began. Not so for the 1997 Geminids. They peak on the night of December 13/14. Unfortunately for meteor watchers, the full moon reigns on this night as well.

Take a look, just the same. There's a chance, though slim, that you'll still spot something. There are ways to increase your chances of being lucky: 1. Pick a site with as little light pollution as possible. Go as far from town as you can, and get to as high an altitude as possible. With the full moon to contend with, you'll want to escape all other light sources. 2. Be prepared to be patient. To glimpse a meteor will require more than five minutes' time spent gazing at the sky. 3. To survive looking longer than five minutes, bring a recliner, a heavy sleeping bag, a parka, a warm hat, hot coffee or soup, and friends who'll dance and sing for your entertainment. Remember to bring binoculars to look at the meteor trains. 4. Try rigging something to your tripod, such as a sheet of cardboard, to block the moon's light.



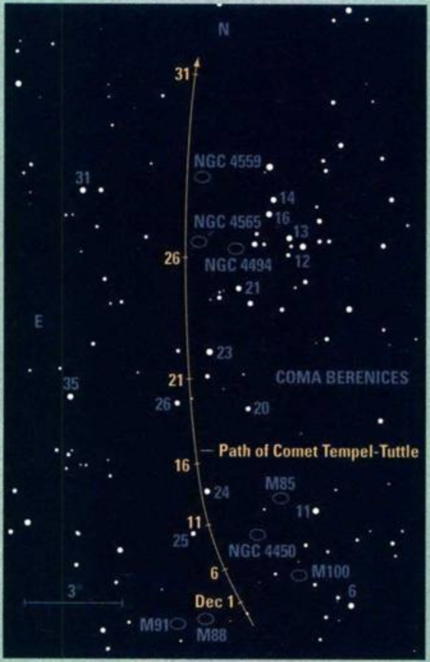
Looking high in the southeast, 1 a.m., December 13

Summer Triangle slides down toward the west. Leading the way is Altair, still 40° above the western horizon an hour after sunset for North American observers. High above it is Cygnus, which will swing to the northwest by mid-evening. Riding along to the east is the Great Square of Pegasus, the Winged Horse, and to its southeast, Pisces the Fish. Due south of the Great Square lies a nice asterism in Pisces called the Circlet, a pentagon-shaped group of five stars, all of 3rd and 4th magnitude.

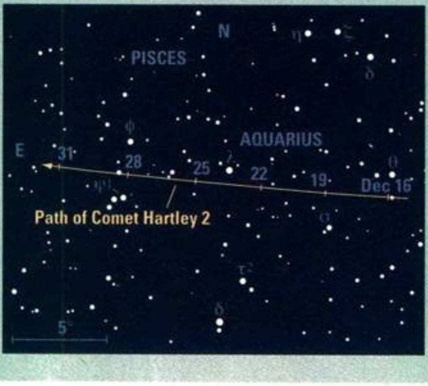
The southeasternmost star in the Circlet is Lambda (λ) Piscium. Two degrees to its northeast lies 19 Piscium, also known as the variable star, TX Piscium. A rather unusual carbon star, this red giant shows strong spectral bands of diatomic carbon and an unusually high abundance of lithium in its atmosphere and is believed to be in an advanced stage of its evolution. TX varies between magnitude 4.8 and 5.2 and is worth looking at since few of these types of stars are bright enough to be seen with the naked eye.

Pisces also sees some planetary action this month. **Saturn** shines humbly at magnitude 0.6, lying to the south of Delta (δ) Piscium. Its westerly retrograde loop against the starry background slows to a halt on December 17, and it resumes its easterly jaunt after that date. Saturn stands out in this region because there are no 1st-magnitude stars in the area. Saturn quietly hides its true nature until you swing a scope in its direction. Its splendid ring system is a sight to behold. The rings span 1.5 times the apparent diameter of the planet's globe along the long axis.

OBSERVER'S CHALLENGE: The Comets of December



Tim Puckett



We've gorged ourselves on two wonderful comets in the last two years, so our hunger should be sated. That's good, because December's offering of comets is more in the nature of a mere taste, not even one course of a meal.

We begin with Comet Hartley 2, located in the southwest after sunset late in the month. This 8th-magnitude comet (seen in the image at far right) lies a bit over 1 AU from the sun and about 0.8 AU from Earth at the end of the month, the reason for its relative brightness. Hartley 2 was discovered by Malcolm Hartley in March 1986.

Comet Tempel-Tuttle, on the other hand, glows high in the southeast before sunrise. It begins the month in southern Coma Berenices, then heads almost due north through the galaxies of that constellation. Tempel-Tuttle will reach the perihelion point in its 33-year orbit around the sun next February, though even then it won't be a powerhouse. However that 33-year figure might ring a bell: It's the interval between Leonid meteor storms. These storms occurred in 1833, 1866, and 1966, and the next may come in either 1998 or 1999.

Tempel-Tuttle was discovered by Wilhelm Tempel of Marseilles, France, on December 19, 1865. Many others observed it in Europe before Horace Tuttle of the Harvard College Observatory independently discovered it on January 6, 1866. The colonials apparently called it Comet Tuttle, since they had no knowledge of Tempel's discovery.

To observe either comet, ensure that you have a dark site with a low horizon. Check to see that your optics are clean and free of dew. Using the lowest power you have, locate the comet's field with the maps. If you see the comet initially, congratulations. If not, avert your gaze — take advantage of the receptors at the periphery of your eye.

Once you've found the comet, rapidly sweep the view back and forth across the comet to make the dim tail present itself. (Your eye sees moving dim objects much better than if they're stationary.) Then travel up the range of powers your eyepieces provide until you've had your fill.

Happy sky viewing and happy winter holidays!

Saturn's main event, however, will undoubtedly be its occultation by the moon on December 8/9. On the west coast, the occultation takes place shortly after 11 p.m. Pacific Standard Time, and after midnight (on the 9th) Mountain Standard Time. The occultation will be visible in the United States; with the exception of the northwest states, it will be visible everywhere west of the Mississippi including Hawaii. Saturn slowly gets hidden by the moon, which is, of course, closer to us.

Four days later, on December 13, the moon moves into Taurus and occults Aldebaran, the eye of the bull. This event is visible from the entire mainland United States except for most of Florida and is also visible from Canada. Observers in northern Florida will experience a grazing occultation. Because Aldebaran is a large star, it will sometimes appear to fade out as the limb of the moon bisects the star for a second or so. The moon immediately occults smaller stars — these points of light vanish in an instant.

By the middle of the evening, as the occultation proceeds, Perseus stands watch overhead, accompanied by the winking demon Algol, the eye of the Gorgon's head. Algol passes almost exactly overhead at 9 p.m. this month. Perseus is surrounded by a host of other noteworthy stars. Unmistakable, lying nearby and to the south, are the seven stars of the Pleiades. Adjacent to Perseus is Auriga the Charioteer. Its 0.1-magnitude star Capella, also known as the Goat Star, is of a similar spectral type to the sun. Within the borders of the constellation, three lovely open clusters are easy targets for binoculars. Grab a pair and scan the triangle defined by Beta (β) Tauri and Iota (ι) and Theta (θ) Aurigae. If you are patient, three faint comet-like objects will appear. M36, M37, and M38 are a few of the finest open or galactic clusters in the sky. M37, the best and brightest of the three, takes the cake.

Taurus the Bull lies south of Auriga while Gemini paces across the heavens to the southeast. Orion lingers just ahead of Gemini. This brilliant region of the sky holds an impressive eight stars of 1st magnitude or brighter. The region, with star clusters and the famous Orion Nebula lying below the three-gemmed belt of Orion, can't be missed.

Gemini is the host of the Geminid meteor shower, arguably the best shower of the year even though it occurs at a time of poorer weather than the more popular summer Perseids. An almost full moon interferes with the peak of the shower on December 13, but activity spans from the 7th to the 17th, so parts of the shower can be seen easily. The Geminids are associated with the Apollo asteroid 3200 Phaethon, perhaps the leftover core of a giant comet that has long since worn out.

Once it passes through this meteor stream, Earth reaches the winter solstice, where the sun is at its farthest point south of the celestial equator and the North Pole is angled away from it. This makes for short days and long nights in the Northern Hemisphere — great for viewing if the weather cooperates.

Lastly, the new moon beats the new year by a hair. On December 30, catch a glimpse of the 29-hour-old moon. It should be easy to spot just thirty minutes after sunset if you have a good view of the southwestern horizon and a clear sky.

Martin Ratcliffe directs the Henry Buhl, Jr. Planetarium in Pittsburgh, Pennsylvania. Rick Shaffer is a science writer living in Sedona, Arizona.

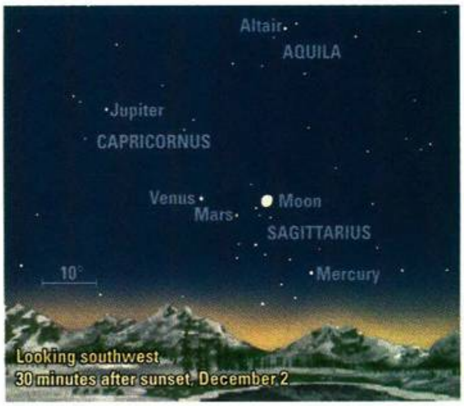
Evening's String of Planets

Depending on your luck with the weather and your selection of a southwestern horizon, the night of December 2 provides four naked-eye planets, two telescopic planets, and the three-day-old moon. But you must start early, just 30 minutes after sunset, so select your site well in advance and arrive before sunset. As usual, try to pick a sight that has a low southwestern horizon free of any sources of heat or turbulence.

Your tour begins with Mercury. You'll find it 7° above the horizon and 7° to the left of where the sun set. (Remember, 7° is the field diameter of standard 7x50 binoculars.) As the sky darkens, you should be able to see it with the naked eye. In the telescope, its yellow-tinged, 7.3"-diameter disk will shine at magnitude –0.2. You may be able to just glimpse its "half-moon" phase.

Next up is the moon, 22° above the horizon. Just below and to the left of it, you'll find Mars shining at magnitude 1.2. Use a high power if you look with a telescope, because its disk is only 4.6" across.

Just above and to the left of Mars is Venus. Its waning crescent disk is 35.7" in diameter and, ever the cosmic lighthouse, its magnitude is –4.6. The next naked-eye planet is Jupiter, that other really bright "star" above and to the left of Venus. Jupiter shines at magnitude –2.2, and its disk is 36.9" in diameter. Since it's 37° above the horizon, Jupiter still warrants a look, as the "after sunset calm" might afford a nice view of its belts and zones.



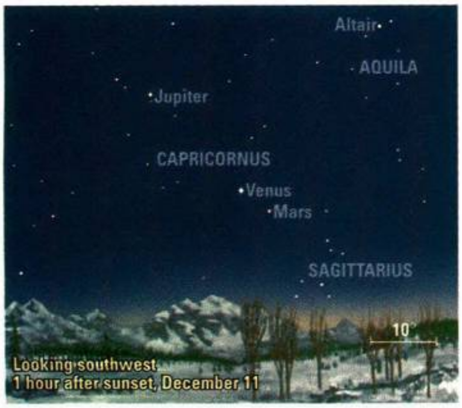
Looking southwest
30 minutes after sunset, December 2

Between Venus and Jupiter you'll find Neptune and Uranus. Neptune shines at magnitude 8.0, so you won't spot it with your naked eye. However, if your inspection of Jupiter reveals momentary great seeing, take a look at both Uranus and Neptune. Speaking of Uranus, it'll be easier to see, since it glows at magnitude 5.8. Many observers have detected Uranus with the unaided eye. You might also.

Venus at Its Brightest

Viewers of the winter sunset will get a view of the third-brightest object in the sky, shining at its brightest in mid-December. On the 11th, Venus shines at magnitude –4.7, 16 times brighter than Sirius, the brightest star (other than the sun) in the sky.

The best time to observe Venus is about 30 minutes after sunset. Its telescopic image may surprise you, as its 41"-diameter disk is only 26 percent illuminated. Why is it so bright? Because it's only 38 million miles (0.41 AU) from us. From this date forward, its disk will grow in size as it wanes toward "new Venus," or inferior conjunction, in mid-January. If you watch it all month, you can see Venus make its most radical change in phase in the shortest time.



Looking southwest
1 hour after sunset, December 11

Venus is ending a long, low apparition that began in late spring. All the while, it has stayed close to the western horizon, surely causing it to be misidentified by some as a UFO.

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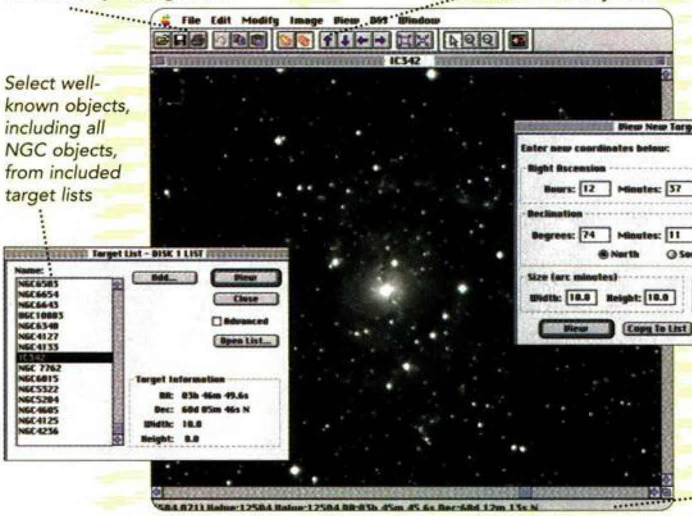

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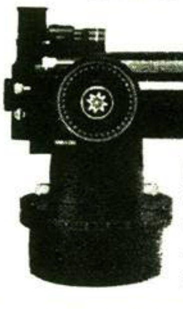

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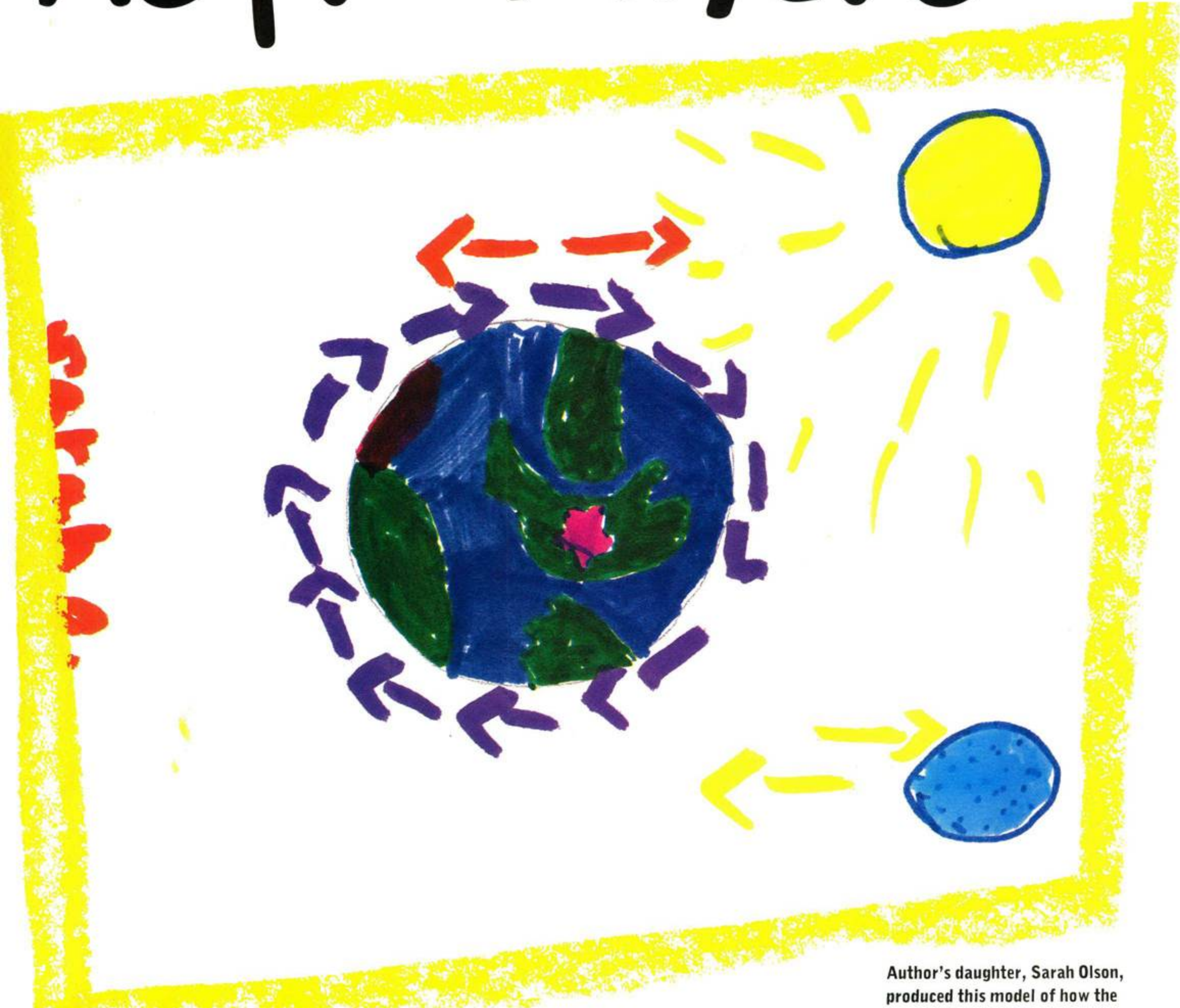


Author's daughter, Sarah Olson, produced this model of how the solar system works.

How to capture the spirit of discovery in your kids

By Steve Olson

I FIRST RECOGNIZED THE IMPORTANCE OF astronomy education in a darkened movie theater. In a comedy that my wife and I saw just before the birth of our son, two characters were sharing a romantic moment in a parked car overlooking Los Angeles when one gazed up at the night sky and said "I've never seen so many stars. There must be dozens of them."

I chuckled loudly — and was immediately shocked to realize that no one else in the movie theater had made a sound. Either no one shared my sense of humor — or everyone agreed that the night sky really does contain only a few dozen stars.

Sitting next to my pregnant wife, I made a promise to myself. When my kids grew up, they would know enough astronomy to appreciate that joke.

It hasn't been as easy as I thought. My two children — now ages seven and six — could probably tell you that there are more than a few dozen stars in the sky. But they're a little fuzzy on the details. My daughter recently told me that stars are "little pieces of space dust floating around in the sky."

Children and astronomy would seem to go together. Planetariums and open houses at observatories are always crawling with kids. And there's something about gazing through a telescope at a faraway nebula that brings out the child in anyone.

But everyone with an interest in astronomy — from the seasoned professional to the occasional amateur — would do well to give some thought to astronomy's future. Surveys show that the average high school student spends only an hour and a half outside each week. In an age of multimedia entertainment, a smudge of light glimpsed through a telescope can be a distinct letdown. Too many kids respond to astronomy as Alan Hale's son did when his father briefly woke him to tell him about the discovery that would make the family name famous: "Dad and his spacey stuff again."

The situation is worse for younger kids. They go to bed too early to see the summer constellations and get too cold to stargaze in the winter. As cities fill the night sky with light, fewer children even get to see the heavens in their full splendor. Many astronomers say that they were drawn to the field by gazing at the stars as children. Will star deprivation lead to less interest in astronomy?

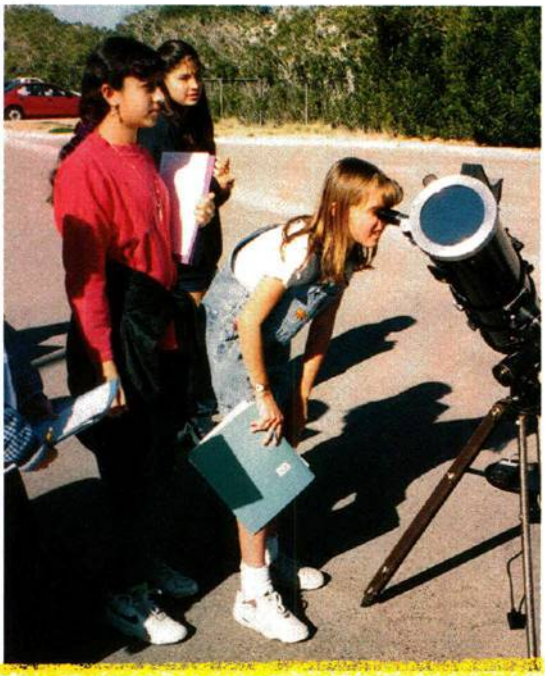
"If you want to have amateur astronomers in society, you have to get them interested as children and adolescents," says Lucy McFadden, an astronomer at the University of Maryland who has been extensively involved in educational activities. "If you don't start them when they're young — at piano or mathematics or drawing or whatever — they probably won't get interested later on."

Many schools don't help much. Elementary schools often don't even teach astronomy, partly on the theory that grade schoolers are not capable of understanding astronomical ideas.

"That was what many science educators thought for years, based on the ideas of Swiss psychologist Jean Piaget," says University of Illinois psychologist William Brewer, who has studied how young children absorb astronomical concepts. "But the world has shifted since then."

The joy shows as kids learn about the planet Earth from a mobile science fair in California. Cosmic Creations brings astronomy fairs to schools and even birthday parties.

Debbie Searle/Sheryl D. Johnson



Project Astro helps train junior solar astronomers at the Townsend Middle School in Tucson, Arizona.

Ginny Beal

Brewer's research shows that even preschoolers develop very elaborate theories about how the world works. The theories are not correct, because young children have not been "Copernicanized," as Brewer puts it. "Adults might think these ideas are dumbheaded, but I don't think so," He says. "Kids are good little scientists. They use the data they have and develop their own theories."

According to Brewer's studies, many children construct a series of distinct ideas about the cosmos as they are growing up. Most begin thinking that Earth is flat, because that is what they see around them. Then, beginning in elementary school, they undergo what Brewer calls "a slow, difficult, agonizing battle to try to make sense of what adults are telling them."

For example, told that Earth is round, many children picture it as a disk. In sailing around the world, Columbus therefore sailed around the edge of the disk. Later, some children think that if the earth is a sphere, we live inside where the candle would go in a jack-o'-lantern.

Finally, most children begin to grasp that we live on the surface of a sphere. But in that case, conclude at least some children, the sun must be going around Earth, since that's what their eyes tell them. "It's remarkable," says Brewer. "Here we have kids who don't know anything about the history of astronomy, and using their own observations they construct a Ptolemaic geocentric cosmology."

The key to breaking through such misconceptions, according to Cary Sneider, the director of astronomy and physics education at the Lawrence Hall of Science in Berkeley, California, is to engage elementary school children in activities that are appropriate for their ages. "Of course kids that age aren't ready to understand galactic structure," he says. "But kids in the first and second grades can see the moon in the sky and draw pictures. They can see that the moon is sometimes around during the day — something that many adults don't know. After another couple of years, they can observe how the moon's phase depends on its position relative to the sun and can make models to explain both phases and eclipses. There are a lot of things you can do in elementary school."

The National Science Education Standards released by the National Research Council last year agree that elementary school children should be exposed to astronomy. The standards state that children in kindergarten through fourth grade should observe astronomical objects "to identify sequences of changes and to look for patterns in these changes." In grades five through eight, according to the standards, students can build on earlier observations to gain "a clear notion about gravity, the shape of Earth, and the relative positions of Earth, the moon, and the sun."

Sneider and his colleagues at the Lawrence Hall of Science have taken the standards to heart. They have developed a series of activities for students in grades four through nine, entitled "Earth, Moon, and Stars," that encourages students to discover for themselves the relations among celestial objects. In one exercise, for example, students imagine that they live at a time when people believe Earth is flat. They then invent flat Earth models that explain how the sun gets from west to east during the night. Finally, they compare their models with the actual shape of Earth and discuss such questions as "What would happen to a rock dropped in a hole drilled between the North Pole and South Pole?"

Sneider has studied groups of children before and after they did the activities and has found marked

A solar system gets measured in toilet paper at a California birthday party organized by Cosmic Creations.

Debbie Searle/Sheryl D. Johnson

decreases in student misconceptions. One surprise: "The younger kids changed their minds more than the older kids," suggesting that older students might have more difficulty learning these concepts as their ideas about the world become more ingrained.

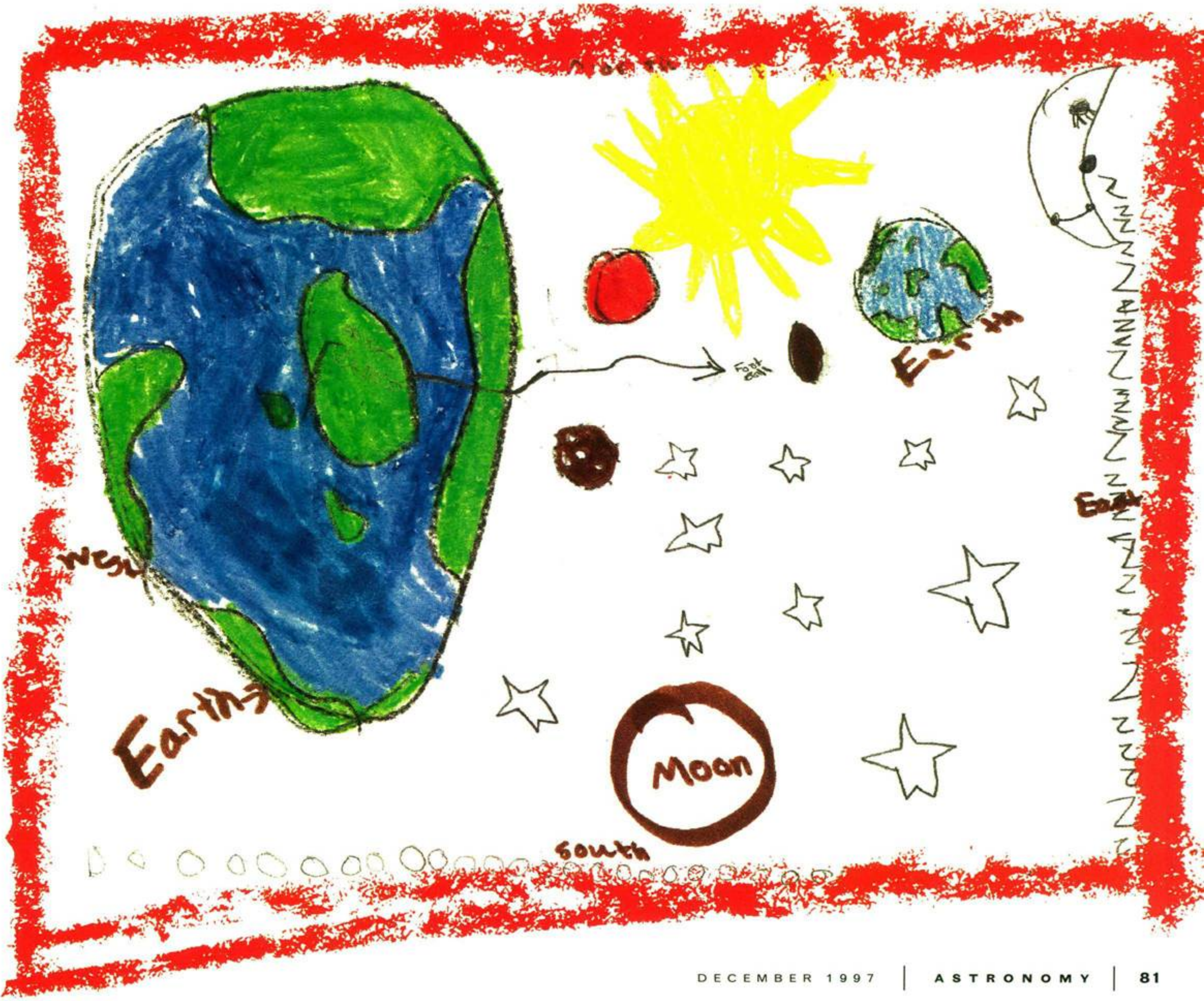
Across the bay in San Francisco, the Astronomical Society of the Pacific also has been emphasizing the importance of reaching students while their attitudes about science are still forming. The ASP is now scaling up Project ASTRO, a program that links professional and amateur astronomers with teachers and youth group leaders in grades four through nine. "The goal is to build a network of astronomers and educators who are both doing astronomy and helping kids learn science," says Jessica Richter, the national coordinator for the project.

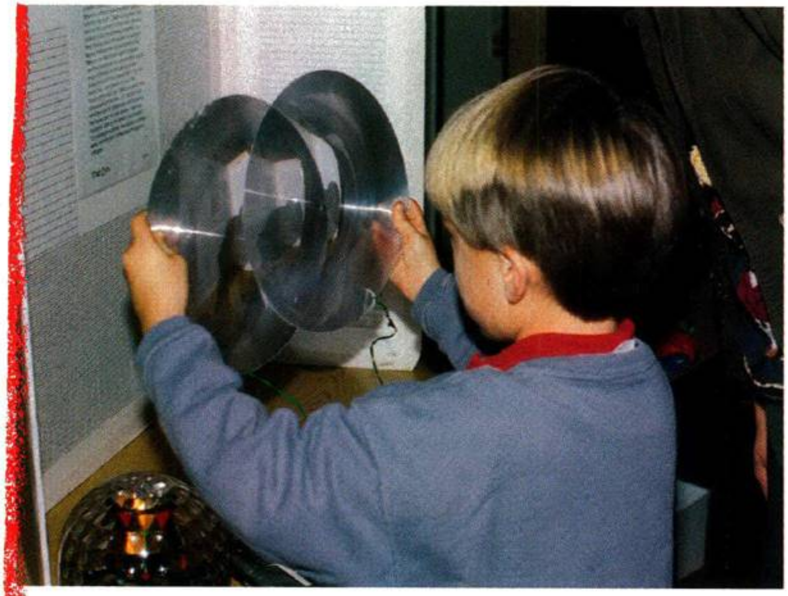
Before going into the classroom, teams of teachers and astronomers attend a two-day workshop to share ideas and plan activities. "The teachers learn the content of astronomy, and the astronomers are exposed to current thinking about how to teach science," says Richter. Both groups "learn how to lead astronomical activities that get kids thinking." With several hundred teachers and astronomers working at six sites nationwide, ASP's goal is to form local coalitions of astronomical and educational organizations that can sustain the projects over time.

All of these educational efforts share a common theme, according to Richter, Sneider, and other educational leaders. They try to get kids doing the same things that astronomers do: observing, recording data, developing hypotheses, and answering questions. Successful astronomy classes draw on the same curiosity and enthusiasm so evident in amateur and professional astronomers.

To anyone with kids, it's not only an obvious approach, it's the only approach likely to produce results. My own kids, for example, attend an elementary school that features a wonderful astronomy module, even though astronomy is not a formal part of the county curriculum. For four weeks, all of the second graders undergo astronaut training in preparation for a promised trip to the

Eight-year-old Alec Putte, of La Petite Academy in Waukesha, Wisconsin, designed this model solar system.





Students at a Southern California mobile science fair get hands-on understanding of polarizing lenses.

Debbie Searle/Sheryl D. Johnson

moon. "What we try to do is capture their spirit of discovery," says Helene Granof, a former medical technician turned elementary school teacher who developed the module. "If we can introduce these concepts in a way that's fun, they'll get a lot out of it — even if they don't understand everything."

Over the course of their training, the second graders do dances to learn about the difference between rotation and revolution. They draw pictures of the moon each day for a month. They read folktales about the moon, study the moon's geography, and plan their trip. Then, on launch day, they go to a darkened stage, watch a movie of Apollo 11, and emerge to find six stations in the auditorium where they can do everything from sampling astronaut ice cream to calculating their moon weights. Says Granof, "When kids leave this school at the end of the fifth grade, many of them say that what they remember best is their trip to the moon."

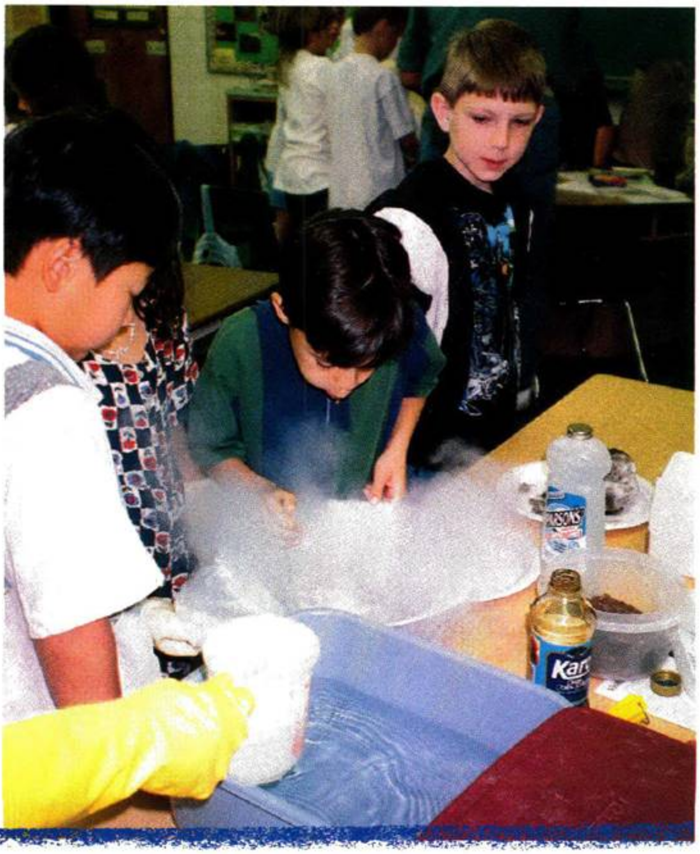
Of course, elementary school children also learn a lot of astronomy outside the classroom — especially if their parents are star buffs. There are more than 200 amateur astronomy clubs in the United States. Where I live — Washington, D.C. — three separate clubs offer regular public viewings, so astronomy events are happening almost every weekend of the year.

There are also more than 1,000 planetariums in the United States, many of which have programs geared for younger kids. An especially valuable innovation in recent years has been the introduction of participatory planetarium shows, especially at small and medium-sized planetariums. "Instead of having kids sit there passively, you have them do things and construct their own ideas," says Philip Sadler, the head of the Science Education Department at the Harvard-Smithsonian Center for Astrophysics. "For example, you can have kids predict where the sun will set, and then the planetarium can test their theories. You can build up a substantial amount of understanding that way."

New media like the World Wide Web and CD-ROMs also have great potential to attract kids to astronomy. At the StarChild site on the World Wide Web, for instance, children can do a number of astronomical activities at two levels, one for elementary school kids and another for middle school and high school kids.

"We believed that if we could put together a good site that kids would trust, they would come back to us later and we could teach them about gamma rays and x rays," says Laura Whitlock, an x-ray astronomer at NASA's Goddard Space Flight Center who is one of the volunteer authors of the site. Already attracting 100,000 hits per month, the site will soon offer a page where kids around the world can compare their observations of the moon — and even have the opportunity to listen to songs about astronomy.

The old media also retain their allure. H. A. Rey's classic book *The Stars* is a favorite in my house — partly because the pictures remind us of Rey's other famous books, the Curious George stories. Another hit is *365 Starry Nights* by Chet Raymo, with a suggestion of something new



Students at Harrelson Elementary School in Tucson, Arizona, work at comet-making with guidance from Project Astro.

Ginny Beal

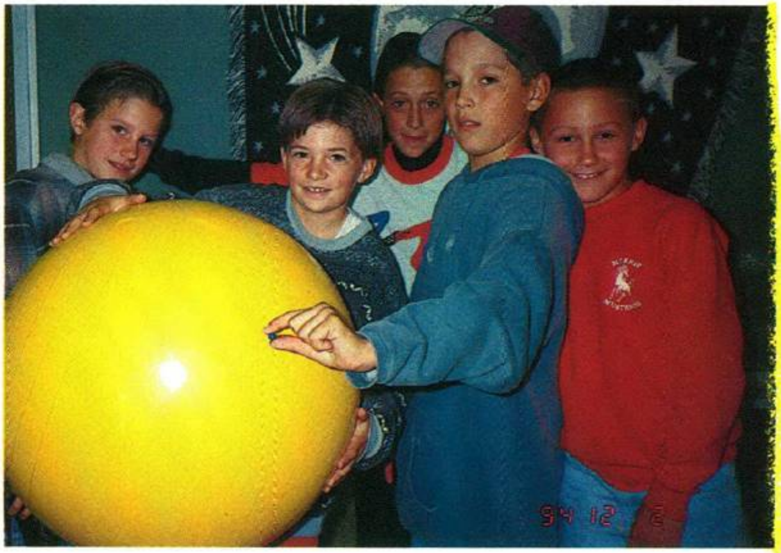
Above, seven-year-old Alex Wagner of La Petite Academy created a solar system with astronauts.

to do each evening. Jay Pasachoff's field guides to astronomy and the solar system for children are good references.

And then there are the stars themselves — available just outside on any cloudless evening. Like many younger children, my kids do just as well without telescopes or even binoculars. Stories, shapes, and star colors seem best at keeping their interest. "You don't need a lot of expensive equipment to get to the stars," says the University of Maryland's McFadden "What's important is to get kids out there and looking up."

So are my kids learning astronomy, as I promised they would? Well, we're making progress. They can find the Big Dipper and Polaris. They can locate Orion in the winter and the star they think is named after the cartoon character Beetle Juice.

At least they're already doing better than most adults. While making the videotape "A Private Universe," Harvard's Sadler, producer Matthew Schneps, and their colleagues asked 23 Harvard seniors, faculty members, and alumni on graduation day to explain the seasons and the phases of the moon. With the supreme self-confidence borne of a Harvard education, 21 got it wrong.



Students compare the Earth to the sun at a California science fair.

Debbie Searle/Sheryl D. Johnson

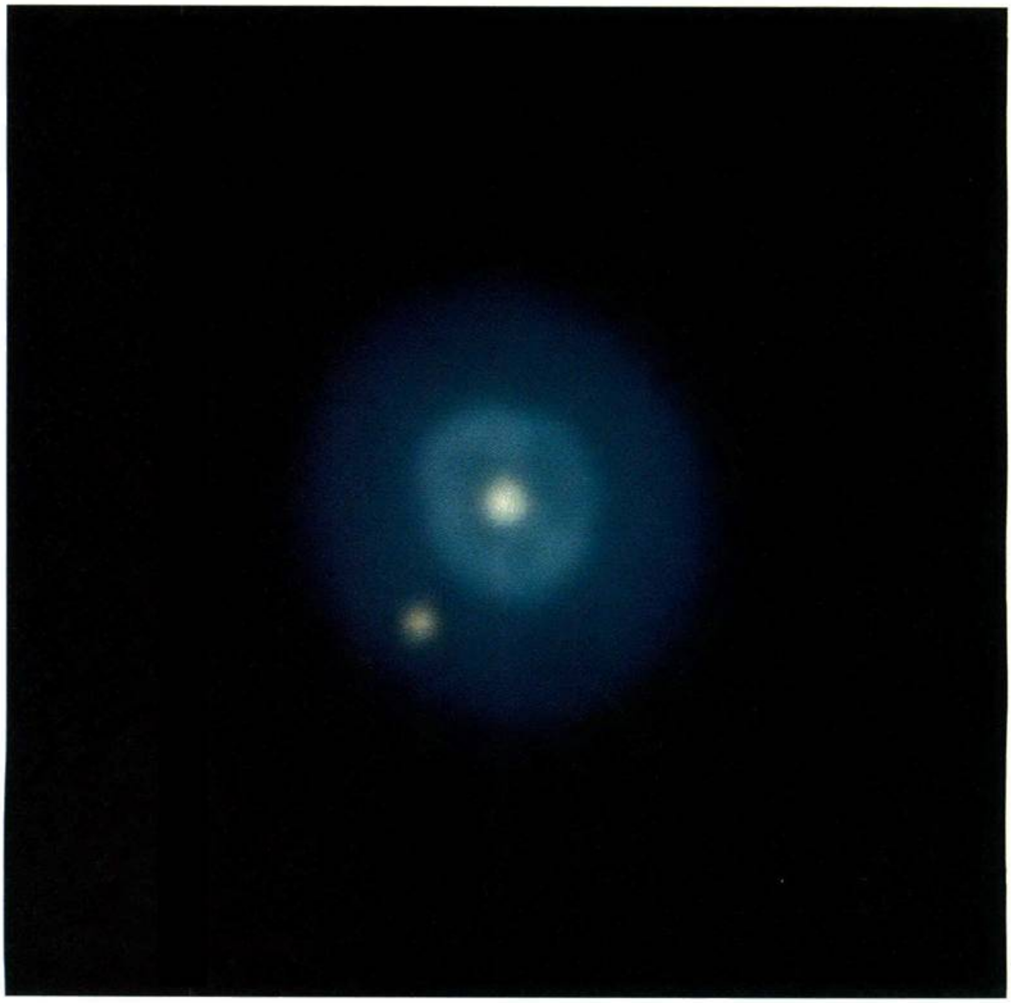
My kids may never graduate from Harvard. But if I have anything to say about it, they'll at least be able to tell you why it gets hot in the summer. ■

Steve Olson is a science writer in Washington, D.C. His most recent book is Beyond Bio 101: The Transformation of Undergraduate Biology Education *(Chevy Chase, MD: Howard Hughes Medical Institute, 1996).*

TOURING A Stellar Graveyard

Boosting the magnification on your scope brings out a multitude of tiny planetary nebulae, the refuse of dead stars.

by Alan Goldstein



NGC 1535 in Eridanus
Rudolph Schild, Harvard-Smithsonian Center for Astrophysics

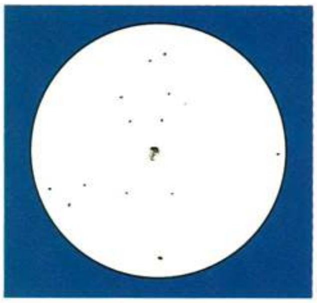
CRANK UP THE POWER. When most people hear that, they think of a blaring stereo. You know the kind. The one that's audible for several blocks. To an astronomical observer, that same phrase has a different meaning — increase the magnification.

Magnification is one of the most abused aspects of hyping telescopes. Telescopes have magnification limits. As a guide, the maximum magnification is 50 times its aperture in inches (3-inch scope = 150x) or twice the aperture in millimeters (80mm = 160x). Exceeding the limit usually means that what you see will be nearly impossible to focus and will show reduced contrast, resulting in a lousy image. On some nights, however, when the seeing (image steadiness) is exceptional, you can exceed the "posted magnification limit."

IC 2149 in Auriga
Preston Scott Justis
(10-inch f/6 reflector, hypersensitized Tech Pan film, 10-minute exposure)

IC 3568 in Camelopardalis
Martin C. Germano
(8-inch f/10 SCT, 103a-F film, 3-minute exposure)

IC 4593 in Hercules
Jeffrey L. Jones
(8-inch f/10 SCT, hypersensitized Tech Pan film, 5-minute exposure)


NGC 2792 in Vela
Sketch by Alan Goldstein
(16-inch f/5 reflector at 300x)

On these rare nights of steady seeing, what will you observe? Consider cranking up the power on some small planetary nebulae and discovering a new world of tiny details. Like the planets that gave rise to their name, many of these objects can be observed with high magnifications at the upper limit of your scope. Planetaries are favorite targets of many observers for a variety of reasons. Watching these objects amounts to peering into the future of the sun. The sun will eventually create a planetary nebula as it enters its final stages in life. Over thousands of years, other sun-like stars of more advanced age have "puffed off" their outer gas envelope to reveal a white-hot, compact nucleus, a white dwarf star. Several hundred of these are visible scattered throughout the galaxy.

Compact planetary nebulae, appearing small either because they are physically small or relatively distant, are among the most vividly colored deep-sky objects. Many are distinguishable from stars at low magnification by their intense green or blue-green color, caused by doubly-ionized oxygen atoms. The colors appear relatively strong because they closely match the peak color sensitivity of human eyes.

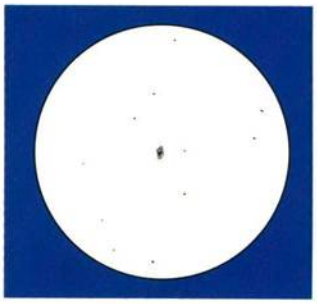
Planetary nebulae derive their energy from their white-hot central stars. White dwarf stars are among the hottest objects in the universe, with surface temperatures at or exceeding 50,000 K. Much of their energy dissipates in the form of ultraviolet radiation. This causes the gas to fluoresce like an emission nebula. They are much more compact, however: While emission nebulae like the Orion Nebula span dozens of light-years, planetary nebulae are typically less than a light-year in diameter.

Planetaries are physically small compared to other deep-sky objects. Their apparent sizes are, for the most part, directly proportional to their distances from us. The diameter of a nebula also relates to its age. After about 50,000 years, such a nebula becomes so distended that it glows very dimly and becomes difficult to observe. The planetaries visible with high magnification are all relatively youthful. They have high surface brightnesses and bear magnification well.

I've prepared a tour of tiny planetaries that samples a wide variety of types, all smaller than 20" in diameter and ranging from 8th- to 13th-magnitude. The order follows right ascension, from the bright constellation Perseus in the winter sky east and southward all the way to Lacerta, nestled neatly in the summer Milky Way. The best high-magnification views come with 6-inch or larger scopes. An accurately polar-aligned, motor driven telescope is almost a necessity for magnifications greater than 300x.

Remember you are magnifying Earth's rotation at the same scale. As a general rule, you can go up to 120x with a 60mm scope, 160x with an 80mm, 200x with a 100mm, 300x with a 6-inch scope, 400x with an 8-inch, 500x with a 10-inch, 625x with a 12.5-inch, 655x with a 13.1-inch, 700x with a 14-inch, and 800x with a 16-inch instrument. To track them down, use a detailed star atlas like *Uranometria 2000.0* by George Lovi, Barry Rappaport, and Wil Tirion (Willmann-Bell, Richmond, 1987–1988) or *Sky Atlas 2000.0* by Wil Tirion (Cambridge University Press, New York, 1981).

TOURING THE STELLAR GRAVEYARD. The first object of our tour is **IC 351**, a 12th-magnitude compact planetary in Perseus. It lies about 3° southwest of the large emission region called the California Nebula (NGC



NGC 6210 in Hercules
Jack Newton
(16-inch f/5 reflector, 12-minute exposure)

NGC 6629 in Sagittarius
Sketch by Alan Goldstein
(8-inch f/10 SCT at 200x)

NGC 6309 in Ophiuchus
Jack Marling
(24-inch f/15 Cassegrain, 20-minute exposure)

NGC 6572 in Ophiuchus
Martin C. Germano
(8-inch f/10 SCT, 103a-F film, 9-minute exposure)

1499). IC 351 is difficult to distinguish with a small scope. With a large telescope it shows a bluish hue. Some 8" by 6" across, it appears nearly stellar at low magnifications and slightly oval when viewed over 150x. The magnitude 15.8 central star may prove to be challenging for a large scope.

Almost as bright as the famous Ring Nebula at magnitude 9.6 is **NGC 1535** in Eridanus. Find it about 4° east-northeast of Gamma (γ) Eridani and 2½° south of 39 Eridani. This nebula is a modest 20" by 17" in diameter. The central star glows at magnitude 11.6, making it easy to spot in small telescopes. This object handles high magnification well, showing its green color. Large instruments show a slightly elongated disk, with a mottled interior. It lies in a pretty rich star field.

Try spotting **IC 418**, a tiny ring-shaped nebula tucked below Orion in the constellation Lepus. Located 2½° east-southeast of Lambda (λ) Leporis, it glows brightly at magnitude 9.3, and its central star is slightly fainter. In small to medium scopes it appears as an oval disk. Larger telescopes show its ring shape, which spans 14" by 11".

Auriga's only bright planetary, located 1½° north-northwest of Beta (β) Aurigae, is **IC 2149**. It glows at magnitude 11.2 and is compact and highly elongated, measuring 15" by 10". A bluish color has been noted in a 10-inch scope by some observers, but the color fades with increased magnification. The central star glows at a relatively easy magnitude 10.7. **NGC 2792** is a planetary nebula in the far-southern constellation of Vela. Its nice disk measures 13" across and glows softly at magnitude 11.2. From the Florida Keys with a 16-inch scope at 300x, I detected a hint of ring structure in this object, with a dim central hole. No central star was observed — it glows meekly at magnitude 15.7. This object may be found a degree and a half north-northeast of Lambda Velorum. The northernmost planetary in our tour is **IC 3568** in Camelopardalis. This magnitude 10.6 circular patch spans 15". The central star is slightly fainter, at magnitude 11.4. Look for a 13th-magnitude star almost in contact with the halo on the western side.

On the Serpens Caput-Hercules border you'll encounter the small and bright **IC 4593**. Both the nebula and central star shine at 10.2 magnitude. At 15" by 11", this nebula stands out in scopes smaller than 4 inches. Larger telescopes and higher magnifications are useful with this object. At 620x with an 11-inch SCT, IC 4593 appeared round, evenly illuminated, and accompanied by a bright central star. **NGC 6210** is the brightest planetary in Hercules (and one of the brightest in the sky) at magnitude 8.8. Its central star glows at magnitude 13.7. This colorful oval spans 20" by 13" and shows some detail with larger instruments and higher powers. It can be found about 4° northeast of the bright star Beta Herculis.

Ophiuchus offers a rich storehouse of planetary nebulae. **IC 4634** is the first one on the tour. This magnitude 10.9 object lies in the southern reaches of the constellation, near Scorpius. Tucked in a rich area of the Milky Way about a degree northwest of the globular cluster NGC 6287, this object appears as an oval patch measuring 20" by 9". The central star is very faint, but at 14th magnitude, it can be picked out with an 11-inch scope. Larger instruments are needed to see this object well.

Less than 2° west of Nu (ν) Serpentis (but still in Ophiuchus) is **NGC 6309**, a brighter twin to IC 4634. It glows at magnitude 11.5 and measures 19" by 10". Look for a star near the end of the long axis. Photos of NGC 6309 resemble a shoe print, with asymmetrical bright patches at the ends of the long axis. The 13th-magnitude central star lies in the middle and appears on the edge of visibility in an 8-inch f/16 scope.

The brightest planetary in Ophiuchus is **NGC 6572**. With a 16" by 13" disk, it is the most circular of the three. Glowing at magnitude 8.1, the nebula shows a vivid green color even in small scopes. Larger instruments show a halo surrounding the disk. The magnitude 12.9 central star is difficult to spot because of the density of the disk.

Nearby Sagittarius lies in the direction of the center of our galaxy. It contains a high concentration of planetaries and several are bright and compact. **NGC 6439** is one of the most difficult described in this article, glowing at a dim magnitude 12.6 and measuring a mere 5" across. NGC 6439 was not difficult to spot in an 11-inch SCT, however. It sits in a rich field; even at very high magnification, I saw a dozen field stars. **NGC 6565** is another tiny planetary in Sagittarius. Located above the "spout" of the teapot, it is slightly dimmer than NGC 6439 at magnitude 13.2 and somewhat larger at 10" by 8". Despite its faintness, it does bear magnification well. I observed it as a pale oval disk at 600x in an 11-inch SCT.

Comparable in size to NGC 6565 is **NGC 6567**, which can be found about 1.5° west-southwest of the open cluster M23. Glowing at 11th magnitude and with an 11" by 7" disk, this oval nebula also sits in a rich star field and bears magnification well. The magnitude 14.4 central star was not observed in an 11-inch at 600x. **NGC 6629** can be found about 3° north and slightly west of the top star of the Sagittarius teapot (Lambda). The nearly circular orb is 16" by 14" in extent and glows at magnitude 11.3. The central star glows dimly at magnitude 12.8 and can be picked up using an 8-inch scope under good skies. The brightest planetary nebulae in Sagittarius is NGC 6818. It lies in the remote northeastern part of the constellation away from the glow of the Milky Way. This 22" by 15" ring glows greenish at magnitude 9.3. The central star is a very faint 15th magnitude. Not far away lies NGC 6822, Barnard's Galaxy, which is much more challenging than NGC 6618.

One of Aquila's brighter planetaries is **NGC 6741**. A compact object measuring 9" by 7", it glows at magnitude 11.4. A rich star field coupled with its tiny size makes this object a challenge to locate. It does bear magnification well. Using an 11-inch Schmidt-Cassegrain at 620x, the oval-shape of this nebula stands out. Nearly forming a right angle with Lambda and 12 Aquilae is the planetary **NGC 6751**. A pale magnitude 11.9 glow, it forms a round disk 21" across. NGC 6751 is readily seen in telescopes as small as 4 inches under good skies. The magnitude 15.4 central star has been reported as difficult to see in 12-inch scope which may attest to its being fainter than 14th magnitude. On the Aquila-Delphinus border lies **NGC 6891**. This oval disk spans 15" by 7", glows at magnitude 10.5, and is easy to spot in a small instrument. The central star is about two magnitudes fainter.

The tiny constellation Sagitta floats within the rich confines of the Milky Way. It contains two small, faint planetary nebulae. **NGC 6879** is a tiny magnitude 12.5 patch only 5" in diameter. It lies in a rich field and resembles an out-of-focus star. I observed it at 620x with an 11-inch SCT. Once acquainted with it, you can locate NGC 6879 under less than perfect seeing. If you've never seen it before, pick out a very steady night without dew on any optical surfaces. **NGC 6886** is another little nebula in Sagitta. At magnitude 11.4, it's somewhat brighter than NGC 6879. I found that at 300x it appears as a distinct oval measuring 9" by 6". The central area is brighter than the periphery. The central star is incredibly faint, glowing at a mere 18th magnitude.

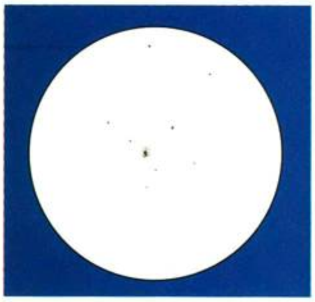
Cygnus contains a full load of planetaries. Three in particular are noteworthy because they stand magnification well, and two are really unusual. The most ordinary of the three is the magnitude 10.9 **NGC 6884**. It is a round disk 6" in diameter that appears brighter toward the center. The magnitude 15.8 central star is beyond the light grasp of most telescopes. **NGC 7026** is located pretty close to Deneb, practically adjacent to 63 Cygni. At magnitude 10.9, it is bright and shows a colorful green hue. The most curious feature is its extreme oblateness, as it measures 25" by 5". Its 14th-magnitude central star is discernible in larger instruments, as is a patch located on either side on the short axis. The oval nature is visible with the smallest telescopes. The most vivid planetary nebula in the summer sky must be **NGC 7027**. The intense green color is visible in small scopes and becomes almost unbelievable in larger ones. It bears magnification extremely well and can be pushed to the practical limit of your instrument. NGC 7027 glows at magnitude 8.5 and measures a modest 18" by 11". It rates as one of the best small planetary nebulae.

The last object is an often overlooked bright planetary in the obscure constellation Lacerta. About 1.5° northwest of Alpha (α) Lacertae is **IC 5217**. It glows at magnitude 11.3 with a central star comparable to that of the famous Ring Nebula, which shines at magnitude 15.4. In modest instruments IC 5217 appears as an evenly illuminated oval spanning 8" by 6".

The sky is rich in small planetary nebulae. These celestial fuzzballs provide an element of fun to year-round stargazing by their varying degrees of challenge. With small scopes, the act of finding some of them offers immense satisfaction. In larger telescopes, "cranking up the power" provides entertainment and details at the limit of your eyes' power of detection. Use these objects to stretch your skills to the limit. ■

Alan Goldstein is founder of the National Deep Sky Observers Society and a frequent contributor to Astronomy.

NGC 6567 in Sagittarius
Martin C. Germano
(8-inch f/10 SCT, 103a-F film, 7-minute exposure)



NGC 6891 in Delphinus
Sketch by Alan Goldstein
(8-inch f/10 SCT at 200x)

NGC 6886 in Sagitta
Martin C. Germano
(14.5-inch f/5 reflector, hypersensitized Tech Pan film, 60-second exposure)

NGC 6818 in Sagittarius
Martin C. Germano
(8-inch f/10 SCT, hypersensitized Tech Pan film, 5-minute exposure)

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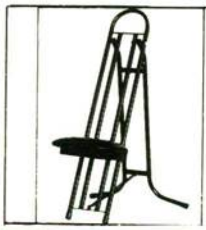

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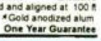

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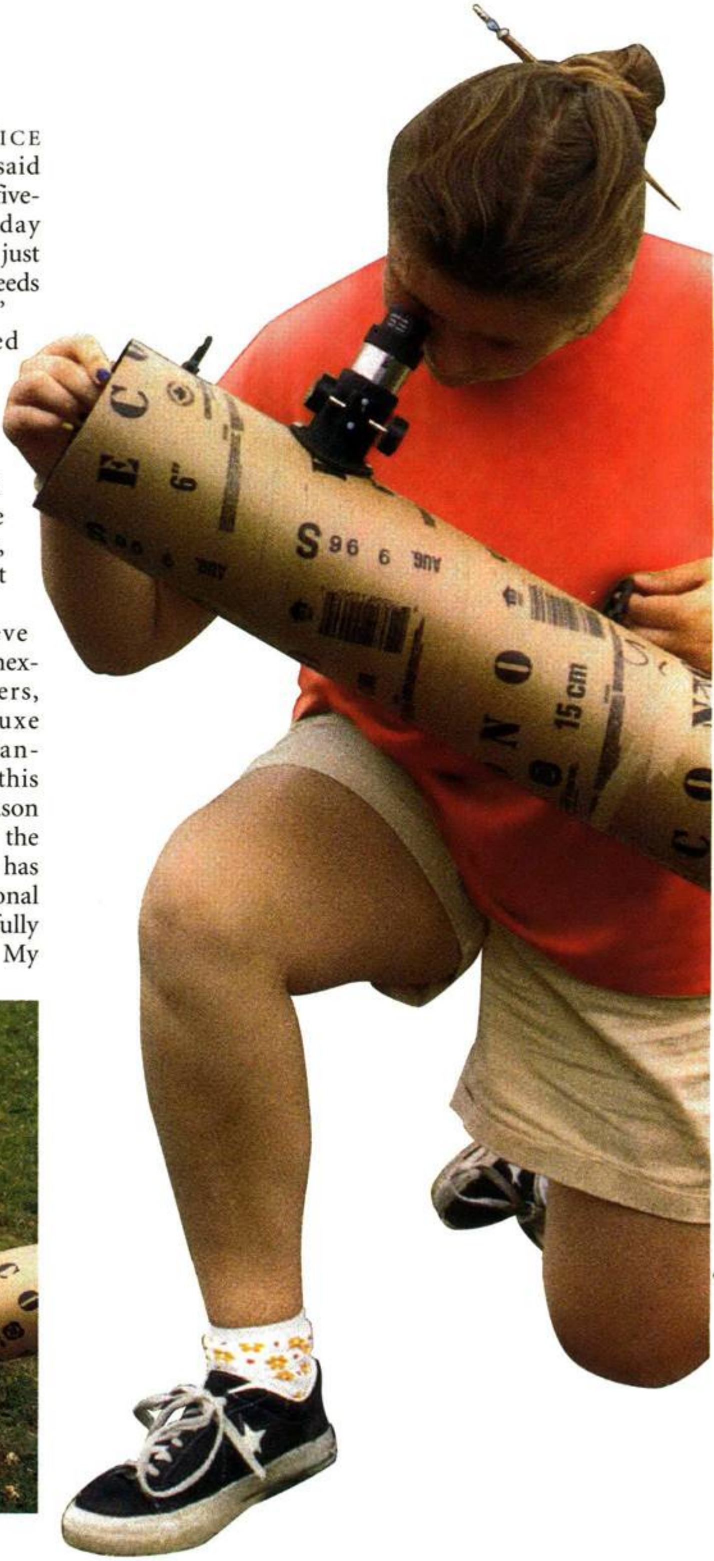
EARLY THIS CENTURY, THEN VICE President Thomas Riley Marshall said "What this country needs is a good five-cent cigar." Were he a modern-day astronomy enthusiast, Marshall might just as easily have lamented, "What this country needs is a good-quality, low-cost beginners' telescope."

How many times has a budget-minded budding astronomer purchased an inexpensive new telescope, only to be stonewalled by its inferior optics and mechanical design? Cheap, subdiameter eyepieces, rickety mounts . . . guaranteed frustration. Within a week, the would-be astronomer is looking into a different hobby, and the astronomical community has lost another potentially productive member.

Enter Canadian telescope-maker Steve Dodson. To satisfy the need for a sound, yet inexpensive telescope for aspiring astronomers, "Stargazer Steve" has designed the Deluxe Reflector Kit, a 4.25-inch f/10 Dobsonian-mounted Newtonian reflector. By making this telescope into an assemble-it-yourself kit, Dodson has minimized the cost and offered the buyer the joy of skygazing with an instrument he or she has constructed. All parts, including an instructional video and completely finished optics, are carefully packaged and shipped in the telescope's tube. My



Heather Harker checks out the telescope constructed by fellow students.

Chris Bodzioch fills the ballast compartment.

Right Start

to-assemble reflector scope kit. **by Glenn F. Chaple, Jr.**

kit arrived in excellent shape with nothing missing. Stargazer Steve did a thorough job of supplying necessary items. I needed only a few basic tools, a bag of aquarium gravel, and a can of flat black paint to get the job done.

As Easy As 1, 2, 3...

Is the telescope easy for a novice to put together? To find out, I assigned the task of assembly to a trio of seventh-graders chosen lottery style from a pool of interested local middle-school students. I was honestly skeptical that such an inexperienced group could do the job, and initially hovered over them like a mother hen. As it turns out, my misgivings were unfounded. The video and backup manual were clear and well-organized in a simple step-by-step format. Very soon in the assembly process, it became obvious that my crew of fledgling telescope makers would do quite well without my interference.

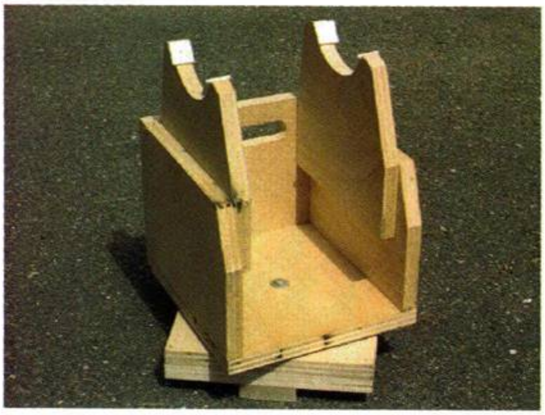
Chris Bodzioch, Carl McClutchey, and Seth Sivak present the completed scope.

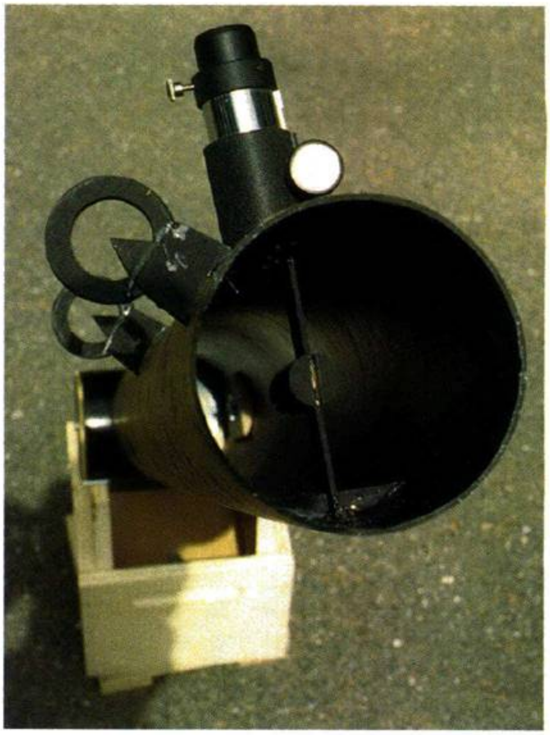
The video was a prototype and lacked the close-up shots Dodson says will appear in a final version. Even without the close-ups, the students were able to assemble the scope with little guidance on my part. Moreover, they seemed to enjoy the task. You could see the excitement mount as their telescope slowly took shape. The only "sticky" area was with final collimation of the main mirror, but a replay of the video and careful perusal of the manual finally cleared up what is often a complicated task for the beginner. During most of the assembly, the students preferred to use the video. (What middle-school kids wouldn't?) Still, the manual is an extremely useful source. Besides well-illustrated assembly instructions, it contains a useful glossary of telescope terms and a list of astronomical resources.

Stargazer Steve says that you can assemble the Deluxe Reflector Kit during the day and use it that very night. This is not an idle claim. We spread the workload over four hour-long after-school sessions — well within Dodson's time frame. If you wish to darken the inside of the tube with flat black spray paint (a glare-cutting measure Dodson recommends) though, add a day to the project.

There are two reasons why the assembly is so quick. First, the aforementioned clarity and simplicity of the instructional video and manual limit the time you'd waste head-scratching and shoulder-shrugging. A second factor was the exquisite craftsmanship of the scope. Many parts, including the holders for the primary and secondary mirrors, the finder sights, and the base assembly, are crafted from high-quality hardwood. All fit snugly together like the pieces of a jigsaw puzzle. After balancing the tube assembly by placing just the right amount of aquarium gravel in a Ziploc bag tucked in a compartment below the main mirror, we were ready to turn the completed Deluxe Reflector on the night sky.

The assembled telescope had some glitches. When the scope was pointed toward the zenith, the mirror collimating bolts, jutting out of the base of the tube assembly, hit the carriage bolt that rises from the base assembly. The problem was quickly rectified by adjusting the bolts so they recessed deeper into the tube assembly. (Dodson has already taken care of this situation by shortening the mirror collimating bolts.)





Individual components are constructed separately and then joined. The base assembly (left) can be seen supporting the tube to form a complete scope (center). The mirror assembly (right) fits snugly into the curves of the base before the tube assembly is secured.

A more critical problem was that the secondary mirror, held on a wooden strut that was glued in place inside the tube, hadn't set perfectly. We could have removed the secondary and reglued it, but, since the alignment wasn't seriously off, we decided to keep things as they were. Because of the importance of proper mirror alignment, I would caution the builder to exert extreme caution during this phase of the assembly process. We also found that the wooden finder sights extend quite a way from the telescope tube and can be bumped and torn loose from the main tube. The damage is not serious and is remedied by simply regluing the sight. If you plan on using this scope for the long term, you may want to eventually replace the wooden sights with a standard finderscope.

It's important to note that this kit is very forgiving. Make a careless mistake in assembly, and it's easy to go back and rectify the situation. If there is a fault with the Deluxe Reflector Kit, it's that assembly is so simple, you may be tempted to rush ahead of the video and miss an important piece of information. It's much better to review each step on the video, read the accompanying piece in the manual, then proceed with the work. My biggest regret during the assembly process was that I wasn't the one doing the job; the students obviously had fun.

Once the scope was assembled, we held an informal star party to see how optically sound and easy to handle our completed telescope was. Murphy's Law of New Telescopes (whenever you get a new telescope, it will be cloudy on the evening you first try it) prevailed, but the clouds didn't cover the sky until after we had managed quick views of the moon and Comet Hale-Bopp.

The scope proved to be easy to operate, although there were some difficulties aiming with the wooden finder sights. Stargazer Steve supplies a 10mm Kellner eyepiece with this kit, which provides a magnification of 114x and a field of view of about half a degree. A lower-power eyepiece (perhaps with a focal length of around 15mm to 18mm) would have generated a wider field, making finding objects easier, while still providing ample magnification for the moon and planets and a variety of showpiece deep-sky objects. To Stargazer Steve's credit, the 10mm Kellner is of the standard 1.25-inch diameter, not the 0.965-inch size that comes with many small scopes. Should the beginner ultimately graduate to a bigger telescope, this eyepiece and any others purchased for the Deluxe Reflector will be compatible with the new scope.

Incoming clouds and aiming difficulties aside, our "first light" adventure was a qualified success. The slight misalignment of the secondary produced no noticeable image distortions. The crescent moon, littered with craters, was a magnificent sight. Hale-Bopp was somewhat smitten by haze, but still evoked gasps of awe. At the end of the session, three seventh-graders went home satisfied that they had successfully constructed a worthwhile astronomical tool. I went home realizing that the Deluxe Reflector Kit would make a great school science project.

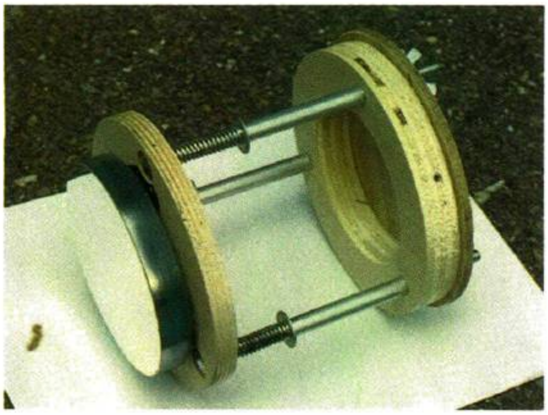
Up To Snuff?

Would the Deluxe Reflector Kit be of use to a more experienced amateur astronomer? Definitely. The assembly phase alone would be an adventure to anyone who has wanted to construct a telescope *but didn't* want to fuss with mirror grinding. The completed 4.25-inch f/10 reflector would serve as a portable "second telescope" to pack in the car when traveling on vacation.

Would the scope's optical quality satisfy a veteran skygazer? On a recent summer evening, I put the scope through some rigorous testing. Again, locating sky objects with the wooden peephole sights and 10mm Kellner required a little effort, but it wasn't impossible. Each target was found by aiming in the general area with the sights and then looking into the eyepiece while scanning with a slow up-and-down, side-to-side motion. In most cases, I hit pay dirt within a minute of searching.

Vega served as my initial optical test. The image was crisper than I had expected, considering the slight misalignment of the secondary. The close pairs that make up Epsilon (ε) Lyrae, the "Double-double," were just resolved with the 10mm Kellner and were easily separated when I switched to a 6mm Orthoscopic eyepiece of my own.

A huge problem with small, inexpensive telescopes, is a wobbly mount that shifts off target as you change eyepieces. Not so with this scope. This unit was so stable that if I tapped the tube while gazing into the eyepiece, the image settled down within a few seconds and remained centered. I checked the light grasp of the Deluxe Reflector by pointing it toward the variable star SS Cygni. A 12.3-magnitude field star — theoretically, about as faint a star as a 4.25-inch scope should be able to detect — was readily visible.



Standard Specifications

Aperture: 4.25 inches (108mm)
Focal ratio: f/10
Focal length: 43 inches (1,092mm)
Length of tube: 48 inches
Size of focuser: 1.25 inch
Included 1.25-inch eyepiece: 10mm (Kellner, 109x)
Finder: Wooden gunsights
Secondary size (minor axis): 1.1 inch
Secondary mirror obstruction (by diameter): 26%
Secondary mirror obstruction (by area): 6%
Total telescope weight: 16.5 lbs, including ballast
Weight of heaviest component (tube): 9 lbs, including ballast
Eyepiece height at zenith: 45.4 inches
Manufacturer direct price: $209, plus shipping and handling
Optional accessories: 7.5mm (Plossl, 146x), $39.95, plus $5 shipping and handling; octahedral base (raises eyepiece zenith 13 inches), call for price

Stargazer Steve, 1752 Rutherglen Crest,
Sudbury, Ontario, Canada, P3A 2K3;
phone, (705) 566-1314; e-mail,
stargazr@isys.ca

Switching from stellar targets to deep space, I checked out M57, the Ring Nebula. The view was about as fine as you can get with a small-aperture telescope. I could actually detect a slight darkening near the center of the nebula. The great globular cluster M13 showed a hint of graininess, indicating partial resolution. Steve Dodson is to be commended for his efforts to make amateur astronomy accessible to the budget-minded individual. His Deluxe Reflector Kit delivers the much-needed "good-quality, low-cost beginner's telescope." And believe me, some veterans will have fun with it too. ■

Chaple, a teacher living in Townsend, Massachusetts, is a frequent contributor to Astronomy *and* Odyssey *magazines. He is also coauthor of the* Edmund Mag. 6 Star Atlas.

Carl McClutchey puts the peephole finder to work.

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Standard accessories include a 6x30 Finderscope, 1¼" Focuser, 25mm SMA Eyepiece – 1¼" (36x), Star Diagonal – 1¼". Weight is 24 lbs.

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The GP mount has a built-in illuminated polar alignment scope for fast polar alignment.

The premium optics of the **GP-C102** are made in Japan to rigid standards. It has a focal length of 1000mm (f/9.8). The **GP-C102-ED** model features Super ED glass to yield exquisite images of very high contrast and resolution with virtually no chromatic aberration. The ED unit has a focal length of 920mm (f/9) and has multi-coatings.

Standard accessories (the same on both models), include a 20mm Eyepiece – 1¼", 6x30 Finderscope with an 8° field and a Star Diagonal – 1¼". Weight is 39 lbs.

Optical tube assemblies of the 4" refractors are available separately and include tube rings, mounting plate and finderscope.

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The glossy black telescope optical tube is made of aluminum. The sturdy altazimuth mount has a slow-motion control rod for vertical adjustments. The rigid, adjustable wood tripod includes an accessory tray.

Standard accessories include a 20mm H – .96" Eyepiece (35x), 6mm SR – .96" Eyepiece (117x), 2x Barlow Lens – .96", 5x24 Finderscope and a 90° Diagonal.

FIRSTSCOPE 60 DELUXE

The same as the Firstscope 60 except that all the .96" items are replaced with a **hybrid 1¼" diagonal and two 1¼" eyepieces** – 25 SMA (28x) and 10mm SMA (70x).

Celestron offers two 60mm equatorial refractors – the Firstscope 60 EQ and the Firstscope 60 EQ Deluxe.

FIRSTSCOPE 60 EQ

Similar to the Firstscope 60 but the focal length for this telescope is 900mm (f/15).

Standard accessories include a 20mm H – .96" Eyepiece (45x), 12.5mm H – .96" Eyepiece (72x), 2x Barlow Lens – .96", 6x24 Finderscope and a 90° Diagonal. Weight is 11 lbs.

FIRSTSCOPE 60 EQ DELUXE

The same as the Firstscope 60 EQ except that all the .96" items are replaced with a **hybrid 1¼" diagonal and two 1¼" eyepieces** – 25mm SMA (36x) and 10mm SMA (90x).

The 1¼" accessories give you sharper images, a wider field of view and better eye relief. Weight is 11 lbs.

Celestron offers a premium grade 80mm (3.1") altazimuth refractor – **The Premium 80.** The premium built optics are made in Japan.

The Premium 80 is an ideal first telescope for the more serious beginning astronomer or terrestrial observer.

Its easy-to-use altazimuth mount includes slow-motion controls in both axes with flex cables allowing quick and easy pointing and tracking. The supplied attractive and very sturdy wood tripod is adjustable in height.

Standard accessories include a 26mm multi-coated Plössl – 1¼" Eyepiece (35x) for a wide field of 1.4°, high quality 6x30 Finderscope and a versatile 45° Erect Image Diagonal – 1¼". Weight is 18 lbs.

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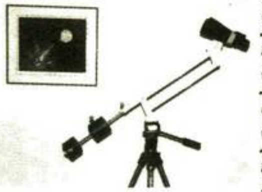

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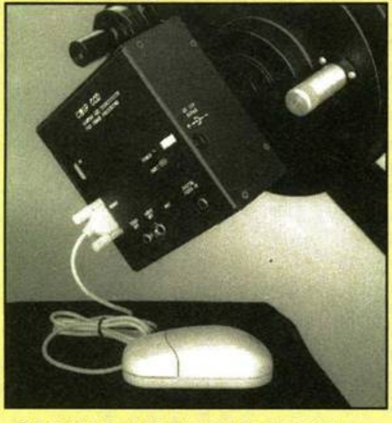

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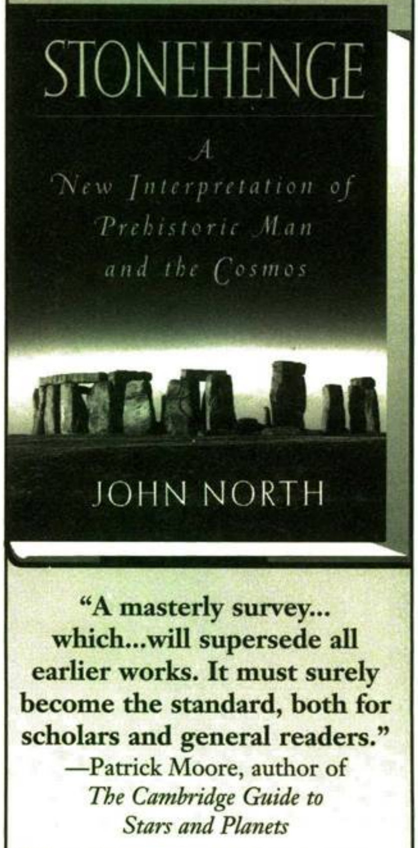

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ask Astro

The message to M13 was sent from the Arecibo Observatory in Puerto Rico. ETs with a similar antenna could hear our message out to a distance of 350 light-years. SETI Institute

Q: Given the present technology in radio astronomy, at what distance can an identical planet detect the radio emission being broadcast from Earth?

— Nick Funk, LaPlace, Louisiana

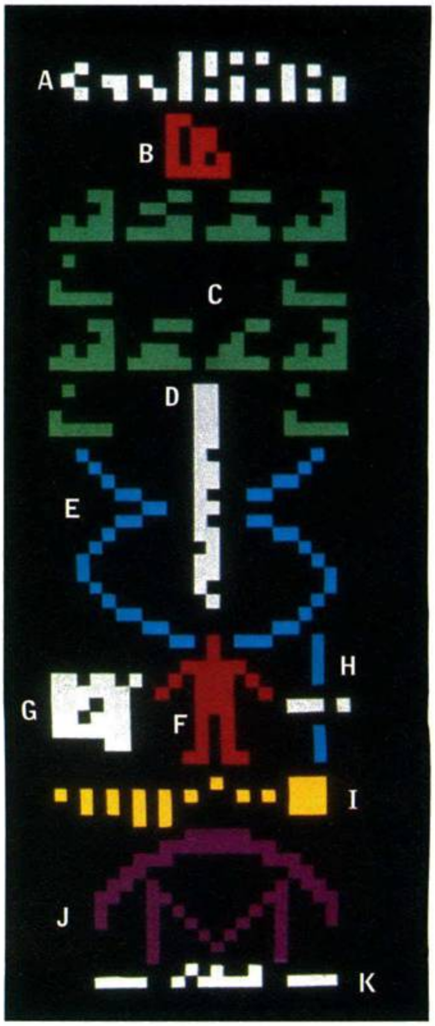
A: Modern *SETI* experiments use large radio telescopes and low-noise amplifiers. But would they be sensitive enough to hear the sort of radio signals that we broadcast into the cosmos?

Alas, the answer depends on how much effort the aliens are willing to make. Among the strongest radio signals ever sent from Earth was the 1974 Arecibo message, a demonstration project that beamed a 1,679-bit picture to possible listeners in the globular cluster M13. The transmission combined the 1,000-foot Arecibo Telescope with a powerful radar transmitter that could be heard at a distance of 350 light-years, assuming the aliens were outfitted with a similarly sized receiving antenna.

The Arecibo message only lasted three minutes. For half a century, however, we've been continually broadcasting TV signals skyward as they shoot over the horizon and into

In 1974, radio astronomers beamed this message toward globular cluster M13. If properly decoded, it reveals a wealth of information about humanity: (A) numbers 1 to 10 in binary code; (B) atomic numbers of hydrogen, carbon, nitrogen, oxygen, and phosphorus; (C) chemical formulas for the sugars and bases in nucleotides of DNA; (D) number of nucleotides in human DNA; (E) double helix of DNA; (F) human being; (G) size of the human population; (H) height of a human being; (I) solar system with Earth displaced toward the human; (J) Arecibo Telescope which sent the message; (K) diameter of the Arecibo Telescope.

Arecibo Observatory/Photo by Tony Acevedo



space. The strong carrier signal that underpins these broadcasts could be picked up at 50 light-years distance if the aliens have covered about 3,000 acres of their planet with TV antennas. Mind you, this is just to detect the carrier. If you insist on getting picture and sound, you'll need an antenna farm tens of thousands of times larger. — *Seth Shostak, SETI Institute*

Q: I have a 14½-inch Dobsonian telescope with a dusty mirror. How do I safely clean this coated mirror? — *Keith Ferrari, Petrópolis, Brazil*

A: First and foremost, clean a mirror only when it's absolutely needed. Wait until there's a noticeable layer of dust before even thinking of washing it. Even then, try blowing off any loose dust with compressed air. If there's accumulated scum or (good heavens!) a palm print, then go the wash route.

Remove the mirror from its mount and transfer it into an extra-wide sink. Blow off any loose dust with compressed air. Carefully rinse the mirror with warm water and then let the sink fill. Add one drop of dishwashing liquid per quart of warm water. Let the mirror soak for five or ten minutes. At no time should you touch the mirror's coated surface; let the soap dissolve away any surface scum. Repeat this process as needed after a warm-water rinse. When the mirror is clean, run a final rinse of distilled water and let the mirror air dry.

If the mirror is carefully protected between observing sessions, you should only have to wash it like this once or twice during the life of your telescope. — *John Shibley*

Q: Would life beyond the solar system be very unlikely because of possible incineration by a nearby supernova? What was the probability of Earth being fried during the 3.8 billion years life has existed? — *Dan Schaefer, Dayton, Ohio*

A: This is an intriguing question, but it is one that is very difficult to answer with any degree of certainty because there are just too many unknowns. If you assume that the rate of supernovae has been constant over the history of the Milky Way Galaxy and that supernovae have been evenly distributed over the volume of the disk, there may have been several thousand supernovae that have exploded within 300 light-years of the sun but only a few within 30 light-years.

We do not know, however, if the actual rate of supernovae has changed over the history of the galaxy or the way in which it has changed across the disk of the galaxy. In addition, we don't know the "death zone" within which a supernova would be fatal to life on Earth, nor do we know much about Earth's protective mechanisms and how they have changed. We also have no idea of the protective mechanisms of life and how it might survive the onslaught of a nearby supernova. Unfortunately, the science needed to answer your question is difficult and has not been done.

Frankly, I am suspicious of any phenomenon that requires Earth to be "lucky," which is a violation of the Copernican principle (which says that the Earth is not special). Obviously, these principles are just that, principles, and they are not science, just guidelines. — *James Kaler, University of Illinois*

The Crab Nebula is the remnant of a titanic supernova. Such explosions could extinguish life on nearby planets. Have we been lucky?

National Optical Astronomy Observatories

CONTACT INFO

Send your questions via e-mail to: askastro@astronomy.com; or write to: Ask Astro, P.O. Box 1612, Waukesha, WI 53186. Please tell us your full name and where you live. *Astronomy* regrets that due to the large volume of mail, we are unable to publish answers to all questions or respond to each one individually.

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NEW! 7'' - 10'' LX50

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LX200 - full computer control w/64K obj. mem.
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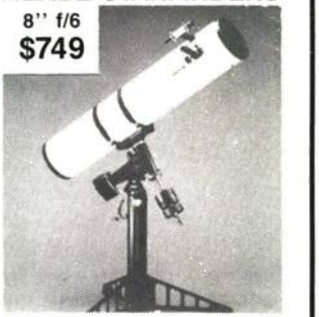

8'' f/6
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See the Meade ad in this magazine for full descriptions. These are complete telescope systems with motor drive & finderscope (equat. only), mount, and 25mm (=48X) eyepiece. New DC motor runs on 4AA batteries.

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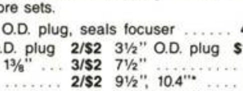

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Rich Zepernick, Cresskill, NJ

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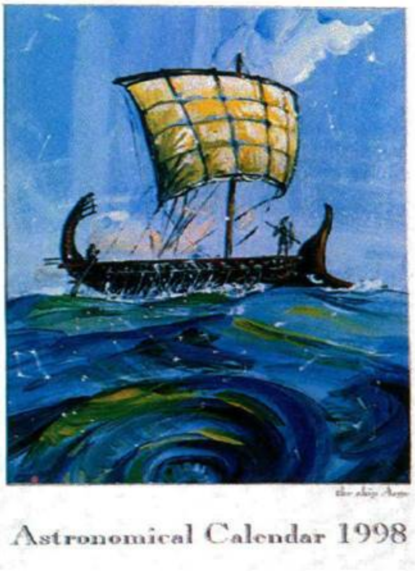

Universal Workshop, Furman University, Greenville, SC 29613, phone, (864) 294-2208; fax, (864) 294-3523; e-mail, guyvernon@aol.com. *The Astronomical Calendar*: $19.95 plus $3 shipping.

(continued on page 104)

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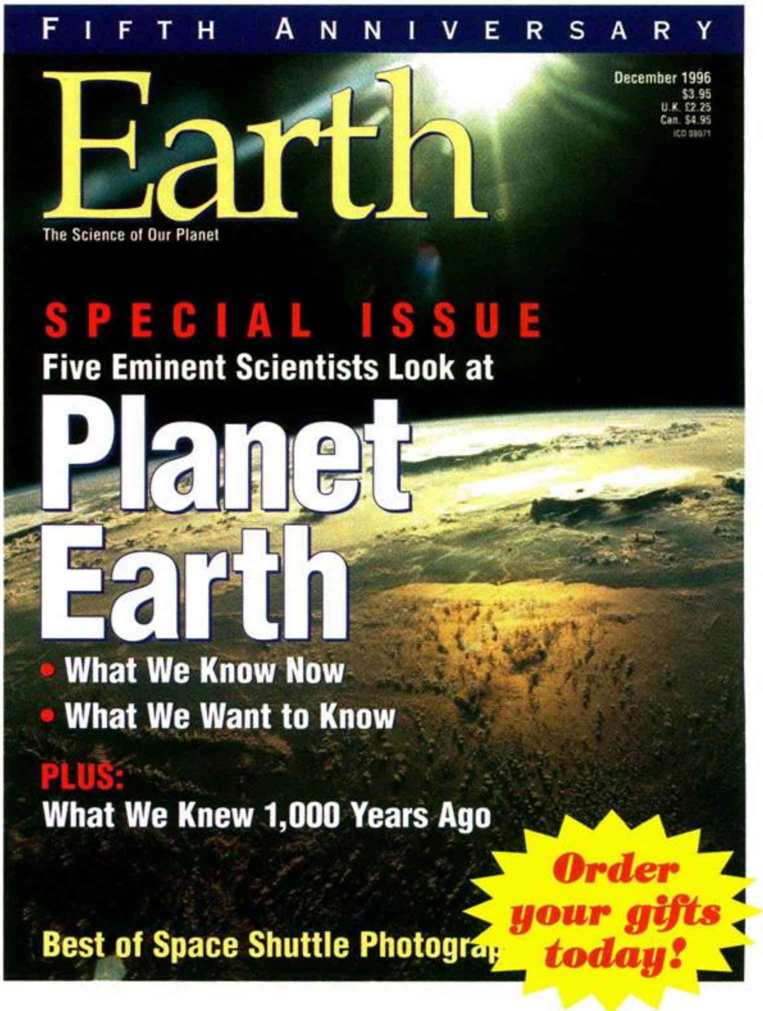

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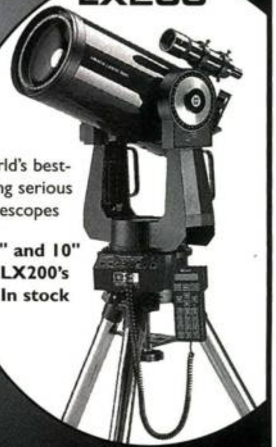

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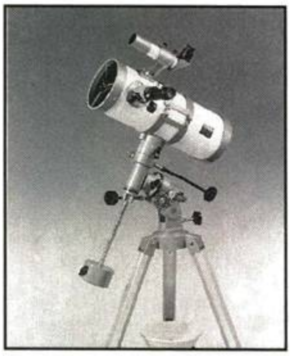

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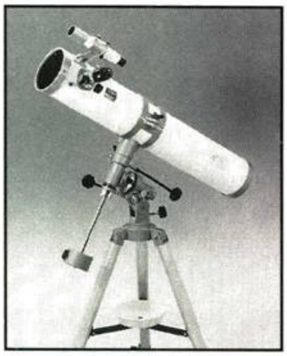

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(continued from page 100)

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The Hubble Space Telescope

BOOKS

Pluto and Charon
Ice Worlds on the Ragged Edge of the Solar System

Alan Stern and Jacqueline Mitton, 232 pages, John Wiley & Sons, Inc., New York, 1998; ISBN 0-471-15297-8, hardcover, $27.95.

Pluto and Charon is more than a book summarizing what we know about a pip-squeak planet in a weird orbit. It's a song about how far and how fast astronomical technology has come since 1965. And it's an unfolding of a new understanding of our solar system that turns what we thought we knew upside down.

The problem was simple. Here's a planet that was discovered only because early observations of Neptune's orbit were slightly off. As Neptune's orbit was refined and as the masses of the outer planets were more accurately determined, it became clear that the calculations leading to the discovery of Pluto in fact were not based on physical realities. From Earth it appears about as large as a grain of sand seen from 1,100 yards away. Under the most favorable circumstances, it is about as bright a candle flickering in Baltimore as seen from Boston (a 300-mile separation). No spacecraft has ever gone there (though co-author Alan Stern is fighting hard for a mission to Pluto). Finding out anything is a challenge.

Still, astronomers have been able to make do brilliantly. Working with traditional light curves and the latest generation CCDs, they surprised us once again. Pluto isn't exactly a planet in the ordinary sense of the word. It is an ice dwarf, one of the largest of millions of such objects that formed in the Kuiper Belt at the time of the solar system's formation. Pluto is not the last planet: It's the first and possibly largest member of the Kuiper Belt, a zone filled with icy planetoids, comets, and debris.

Most of the time the atmosphere of Pluto lies frozen on the rocks. The range of its distance from the sun, however, is greater than the distance from Earth to Uranus. At perihelion, those frozen gases sublimate, and Pluto has an atmosphere (mostly nitrogen, just like ours). Then as Pluto moves farther from the sun, the atmosphere freezes again. The frost composed of methane will be as "white as snow." Ultraviolet radiation over the years will turn it dark. But at perihelion the methane will sublimate, to condense out again as white frost. Pluto might actually grow brighter as it moves away from the sun.

Only in 1978 did astronomers at the U.S. Naval Observatory accidentally discover Pluto's companion, Charon. (Naval Observatory astronomers found the two moons of Mars a century earlier.) A Swedish astronomer, Leif Andersson, was the first to realize that Pluto and Charon were about to go through a series of occultations, something that happens only once every 124 years. Astronomers would be able to nail Pluto's actual size and albedo.

One of the nice touches in the book is that Stern and Mitton tell us something about each astronomer. Andersson, for example, put himself through college by competing in television game shows. They also tell us that he died of lymphoma in 1979, at the age of 35. The book flaps tell us a little something about the authors themselves. Alan Stern is a planetary astronomer at the Southwest Research Institute in Boulder, Colorado, and Jacqueline Mitton is

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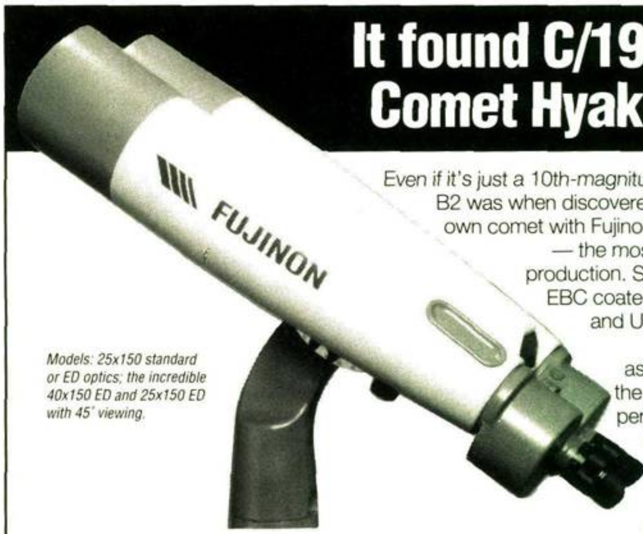

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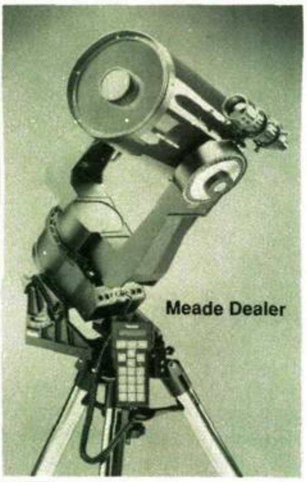

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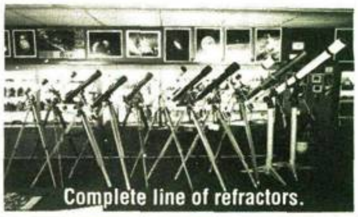

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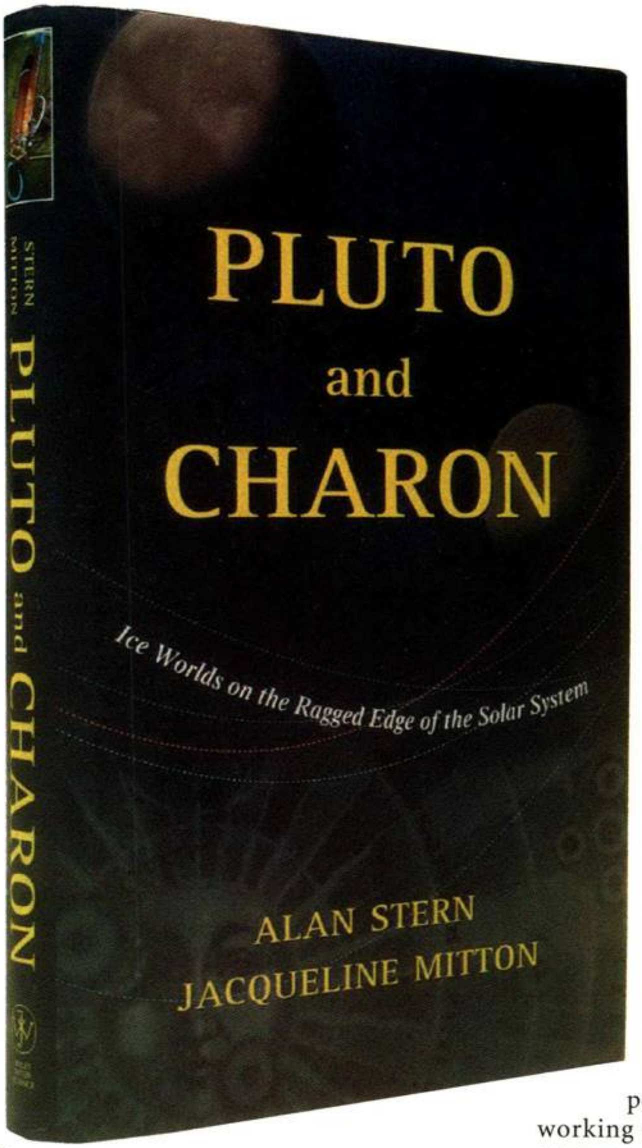
The authors lead us through the process that led astronomers to believe that Charon was formed when something big hit Pluto (just as they believe our moon resulted from something hitting the Earth). They also believe that the axial tilt of Uranus (more than 90 degrees) and Neptune are the result of major collisions. These things "are the smoking guns," Stern and Mitton tell us, "of long-past events indicating that the ancient solar system made small and moderate sized planets in great numbers."

Some had expected it. At mid-century, a couple of astronomers wondered in print why it seemed the solar system stopped short, with the exception of tiny Pluto, at Neptune. One of them was Gerard Kuiper. The instrumentation of the day was not up to searching for ice dwarfs beyond Pluto. Only in the late 1980s did the quest begin. It was four years later, in 1992, when David Jewitt and Jane Luu found a faint spark crawling across the star fields in their CCD. This was 1992QB1, affectionately nicknamed Smiley for the LeCarré character, an object perhaps 140 miles across and possibly even spherical in a lumpy kind of way. Extrapolating from the number of square degrees of sky scanned in order to find Smiley to the entire ecliptic, astronomers postulate the existence of 50,000 or more such objects of this size or larger. Hubble photographs suggest the presence of millions of cometary nuclei as well. This crowded stretch of trans-neptunian space is known, fittingly, as the Kuiper Belt.

Little Pluto, smaller than our moon, has had much to teach us. And Stern and Mitton use the running narrative of Pluto research to explain in comfortable, everyday language how such work is done. The occasional awkward patches are balanced by passages that transcend the task of information transfer. — *John P. Wiley, Jr.*



Other Books

Cosmic Clouds: Birth, Death, and Recycling in the Galaxy

James B. Kaler, 252 pages, W. H. Freeman and Company, New York, 1997; ISBN 0-7167-5075-9, hardcover, $32.95.

▶ University of Illinois astronomer James B. Kaler, an expert on stellar evolution and a frequent contributor to *Astronomy*, follows up on his critically acclaimed 1992 book *Stars* with another highly engaging and informative book in the Scientific American Library Series. *Cosmic Clouds* deals with the various nebulae associated with stars, primarily stellar nurseries and planetary nebulae (which surround dying stars). Kaler explains how these clouds are intimately connected with each other and with us. He likens the galaxy to a great recycling engine, as stars form from the ashes of dead stars to forge the elements that will ultimately build future generations of stars, planets, and possibly life. The book is beautifully illustrated with diagrams and photos, including recent images from the Hubble Space Telescope.

Bright Galaxies, Dark Matters

Vera Rubin, 236 pages, AIP Press, Woodbury, New York, 1997; ISBN 1-56396-231-4, hardcover, $29.95.

▶ In 1965, Vera Rubin became the first woman scientist permitted to observe at Palomar Observatory. Her work in the years since, most notably on galactic motion and the probable existence of dark matter, has made her one of the most distinguished and accomplished women in contemporary science. *Bright Galaxies, Dark Matters* tells two tales: the historical and scientific journey toward our present understanding of the structure and composition of the universe and Rubin's personal journey as a woman working at the forefront of modern astronomy. Included in the first of the book's four sections are several of Rubin's scientific papers on the motions of stars within galaxies. She also examines the tools of her trade, from star charts to the Hubble Telescope, and follows that with additional scientific papers, which present evidence gathered from her study of galactic motion to support the theory that much of the matter in the universe is dark. The concluding section is a candidly introspective look back on the demands and rewards of her career, spiced by enchanting portraits of colleagues, friends, and other notable women scientists. Though at times far from light reading, Rubin's book offers a glimpse at the beautiful interplay of science and humanity, one worth your time and attention.

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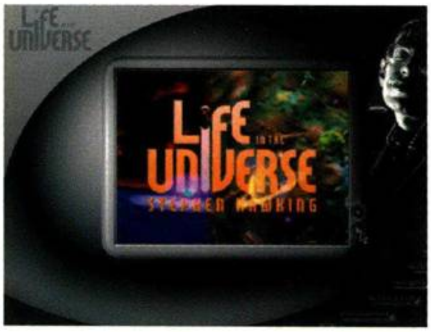

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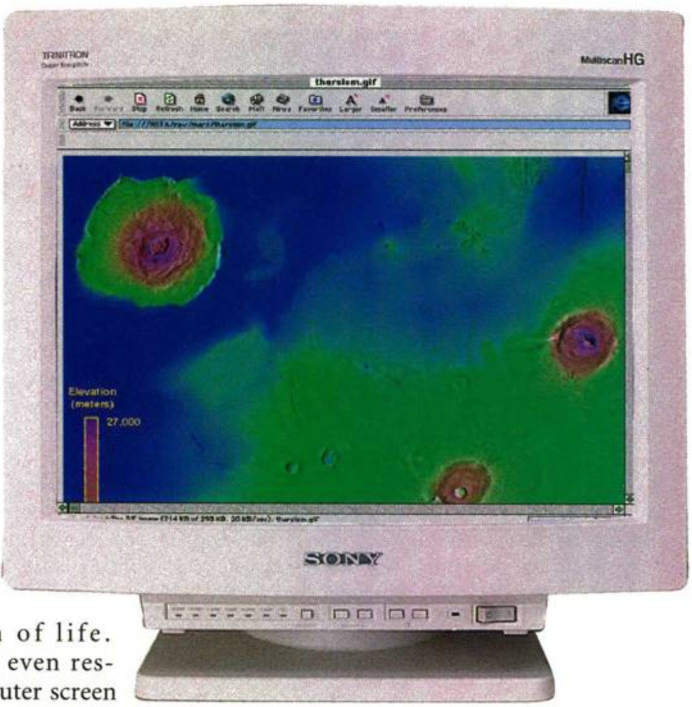

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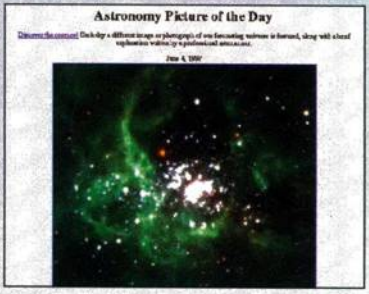

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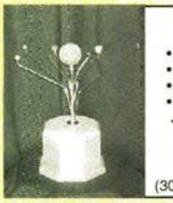

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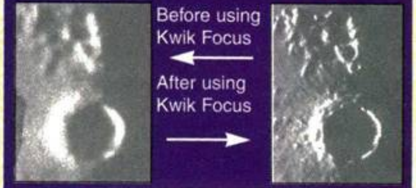

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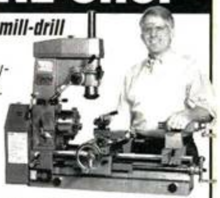

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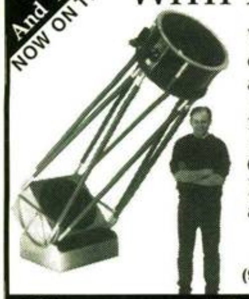

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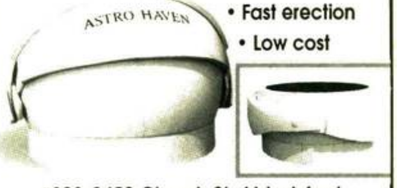

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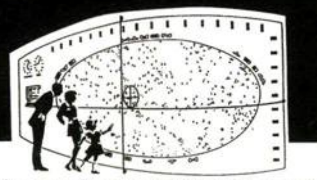

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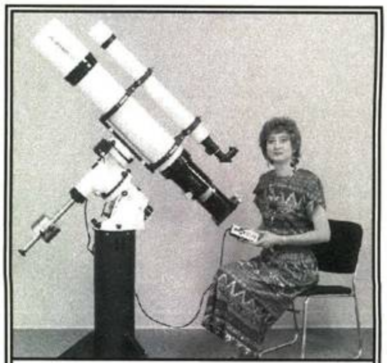

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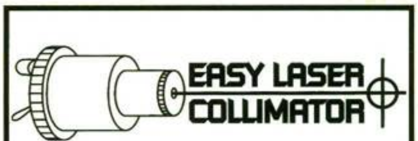

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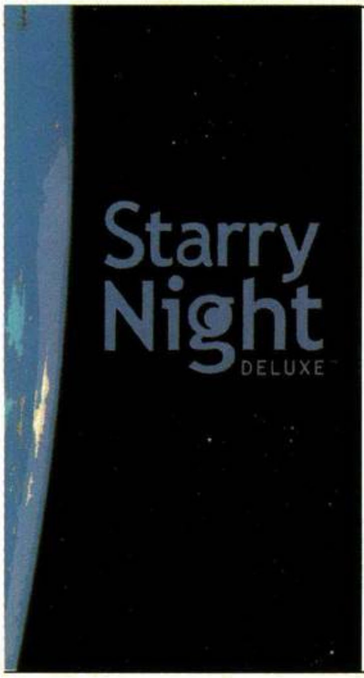

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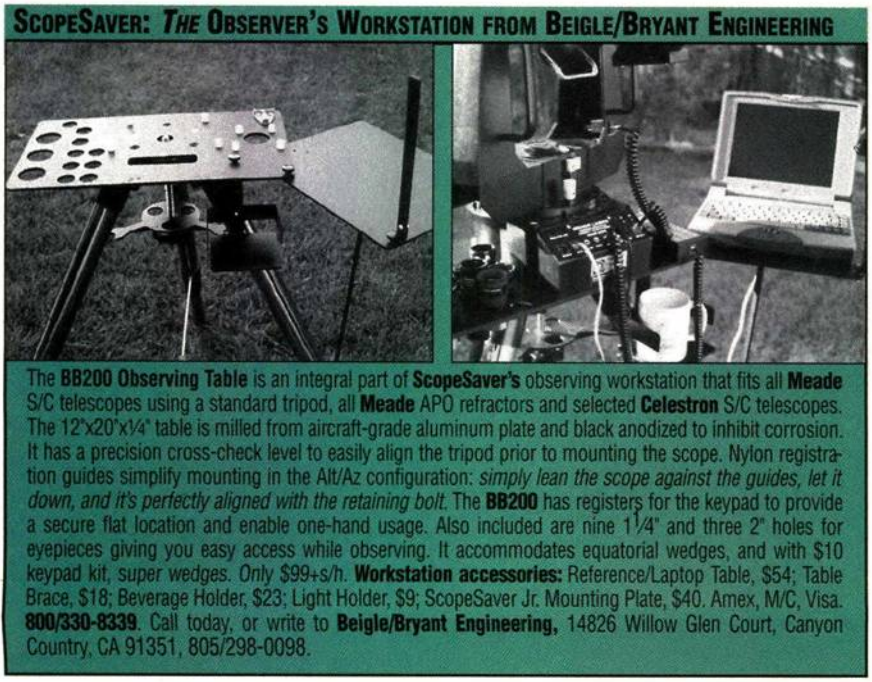

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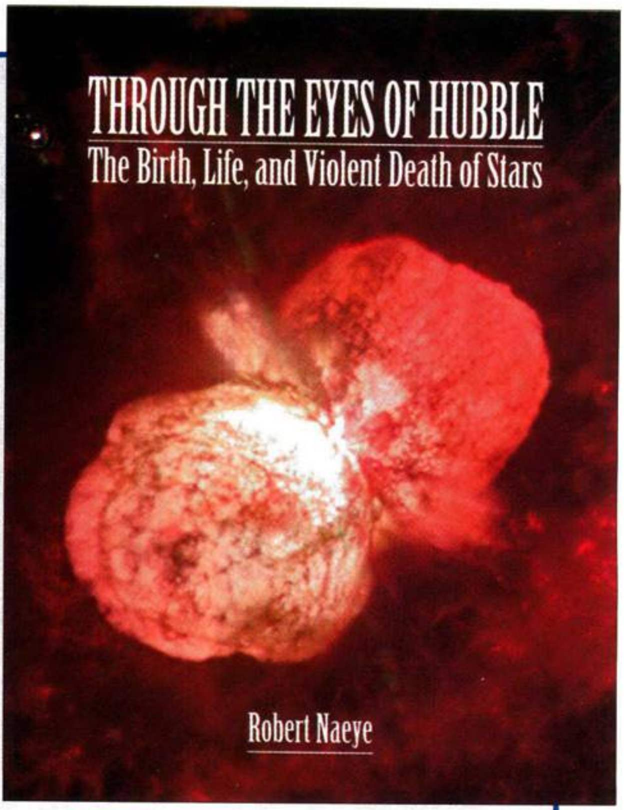
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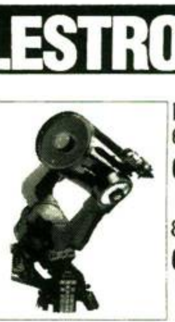

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This may be the time to expand your activities beyond solo observation — enroll in an astronomy or photography course, become involved with the local astronomical society, attend a convention, or plan a family visit to a nearby planetarium or observatory.

One thing about astronomy is certain: The opportunity to gain knowledge is about as limitless as the universe.

NOVEMBER 29

Star Lecture: X-Ray Vision

▶ National Air and Space Museum, Smithsonian Institution, Sixth Street and Independence Avenue, S.W., Washington, D.C. Dr. Ed Frederick, curator of astronomy at the New England Science Center in Worcester, Massachusetts, discusses the history of x rays and their applications in science and industry. For more information, call (202) 357-2700.

DECEMBER 3–6

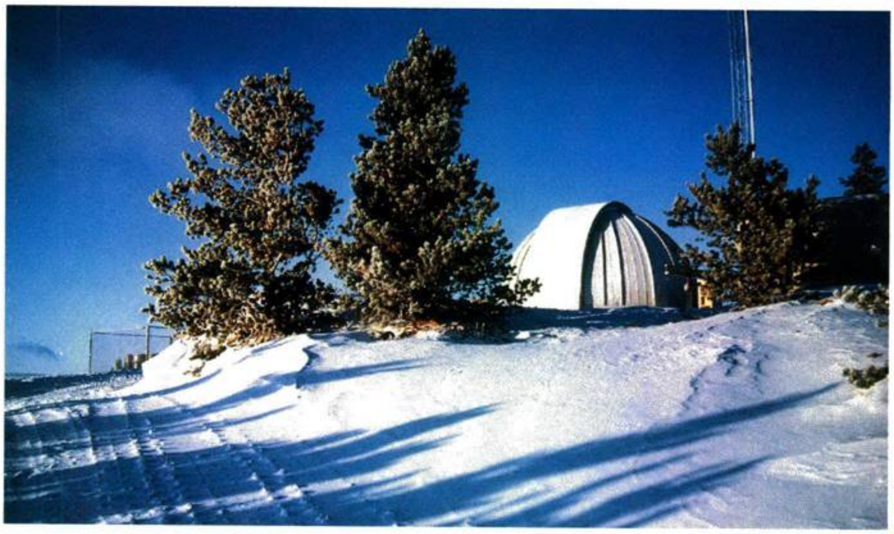
Star Party

▶ Lake Kissimmee State Park, Florida. Sponsored by the Ridge Volunteer Astronomers and Lake Kissimmee State Park. Contact George Aycrigg, 14248 Camp Mack Rd., Lake Wales, FL 33853; (941) 696-3472 or (941) 696-1812; e-mail, gda@gate.net.

DECEMBER 6–7

Fifth Central American Congress for Amateur Astronomer Associations

▶ Centro Loyola, Calle Teotl, Colonia Altos de Guadalupe, San Salvador, El Salvador. Sponsored by the Salvadoran Astronomy Association. Contact Ana-Gui Reyes, VIPSAL #1416, P.O. Box 02-5364, Miami, FL 33102-5364; phone in El Salvador, (503) 278-8888, ext. 3117; fax, (503) 278-3079; e-mail, anagui@sal.gbm.net.



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▶ Adler Planetarium, 1300 South Lake Shore Drive, Chicago, Illinois 60605. Contact (312) 322-0304, 24-Hour Information Line (312) 922-STAR; website, http://astro.uchicago.edu/adler/.

JANUARY 6–10

American Astronomical Society Convention

▶ Washington Hilton and Towers, Washington, D.C. Speakers include NASA Administrator Daniel Goldin and Vice President Al Gore. For registration information contact the International Conference Management, 4709 Montgomery Lane, First Floor, Bethesda, MD 20814; (301) 913-9338, ext. 308; fax, (301) 913-5452; e-mail, aas98@conference.com; website, http://www.aas.org.

JANUARY 29–FEBRUARY 1

The Orange Blossom Special Star Party

▶ Hickory Hill Observing Complex, near Brooksville, Florida. Sponsored by the St. Petersburg Astronomy Club. Contact Dennis and Ellen Farr, 8811 West Broad Street, Tampa, FL 33615; (813) 884-9111.

JANUARY 26–FEBRUARY 1

Winter Star Party

▶ West Summerland Key, Florida Keys. Sponsored by the Southern Cross Astronomical Society. Contact Mike Barrs or Therese Rubenstein at 3403 Poinciana Avenue, Miami, FL 33133; (305) 441-2428; e-mail, wsp@scas.org. For information about accommodations call (800) FLA-KEYS.

MARCH 7

Wagman Winterfest

▶ Nicholas E. Wagman Observatory, Mahaffey Road, Deer Lakes Regional Park, Russellton, Pennsylvania. Free. Contact Pete Zapadka, (412) 224-2510; e-mail, pzapadka@fyi.net; website, http://trfn.clpgh.org/orgs/aaap.

MARCH 16–20

Lunar and Planetary Science Conference

▶ NASA Johnson Space Center, Houston, Texas. Cosponsored by the Lunar and Planetary Institute and the NASA Johnson Space Center. Contact LeBecca Simmons, 118 LPI Publications and Program Services Department, 3600 Bay Area Boulevard, Houston, TX 77058-1113; (281) 486-2158; e-mail, simmons-@lpi.jsc.nasa.gov.

MARCH 26–29

Peach State Star Gaze

▶ Held at Camp McIntosh, Indian Springs State Park in Jackson, Georgia. Sponsored by the Atlanta Astronomy Club. Contact Ken Poshedly, 3440 Everson Bay Court, Snellville, GA 30278; (770) 979-9842; e-mail, ken.poshedly@mci2000.com.

Vulcan Chasers (page 42)

In Search of Planet Vulcan: The Ghost in Newton's Clockwork Universe, by William Sheehan and Richard Baum, (Plenum, 1997). A thorough and enjoyable overview of the great Vulcan chase.

Digging for Gold (page 48)

Asteroid – Earth Destroyer or New Frontier? by Patricia Barnes-Svarney, (Plenum, 1996). A comprehensive discussion of the study of asteroids, their potential use as resources, past impacts with Earth, and the effect of a collision on our planet's present-day ecology.

Astronomy's Feisty Old Man (page 54)

Lonely Hearts of the Cosmos, by Dennis Overbye, (HarperCollins, 1991). A magnificent introduction to cosmology, the book contains a great deal of information about Sandage and the debate over the Hubble Constant.

Raising Astronomers (page 78)

Albedo to Zodiac, by Guy Ottewell, (Universal Workshop, 1996). A glossary of astronomical names and terms, with their pronunciation, origin, and meaning.

Star Tales, by Ian Ridpath, (Universe Books, 1988). A fascinating guide to the Greek mythology surrounding the constellations with beautifully illustrated star maps.

The Stars, H. A. Rey, (Houghton Mifflin, 1976). A guide to the constellations and sky charts written and illustrated in an easy-to-understand format.

Beginner's Guide to Amateur Astronomy, by David J. Eicher, (Kalmbach Books, 1993). From the publishers of *Astronomy*, this book describes what backyard observers can see in the night sky using binoculars and telescopes. Includes lists of telescope manufacturers, North American astronomy clubs, the Messier catalog, and fundamental deep-sky objects.

CONTACT

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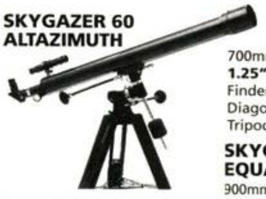

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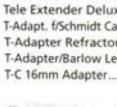

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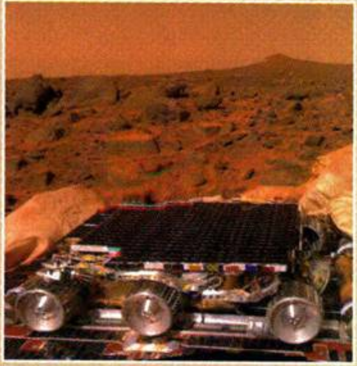
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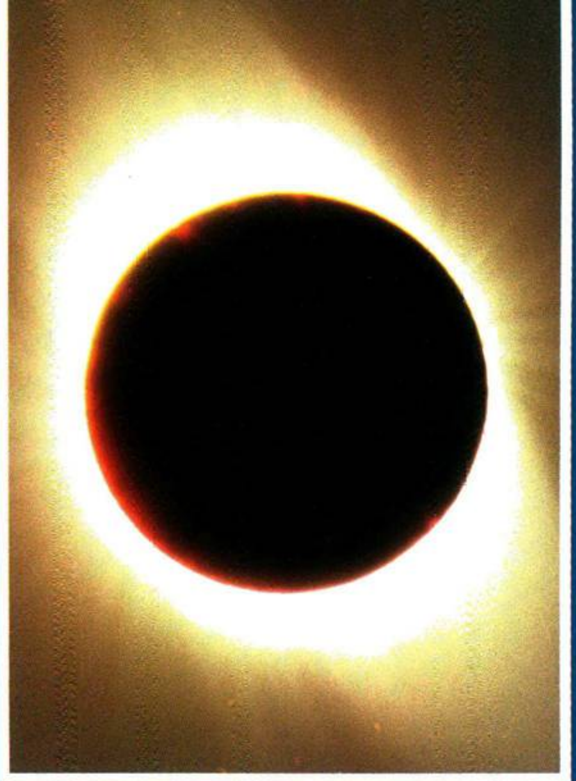

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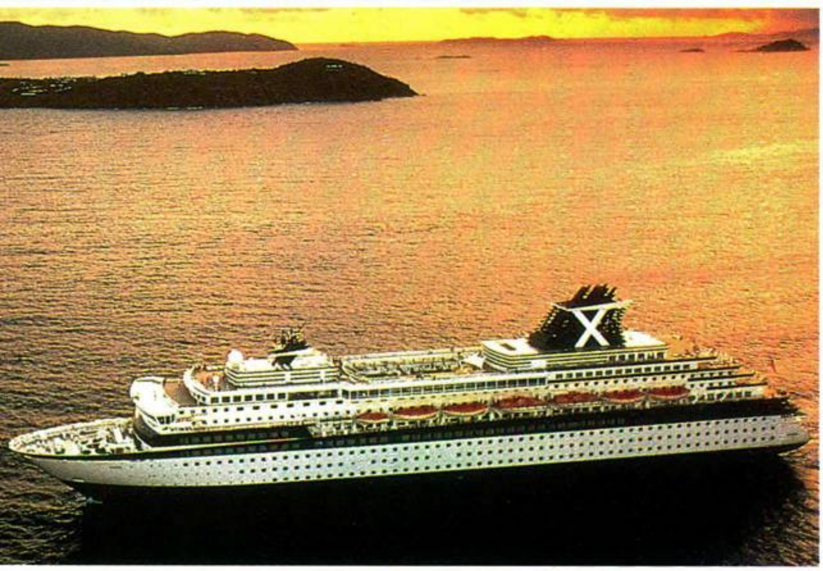

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50 Years of Meteors

A childhood fascination evolved into a lifelong passion for this meteor observer.

► It began in the summer of 1948. Our family was returning from Lake Erie when a fireball blazed overhead. To me, an eight year old, the concept of a rock coming from space and lighting up the sky was incredible — and the beginning of a lifelong career.

The rest of the summer of '48 was spent in the backyard watching meteors. Blessed with dark skies, I counted more than a thousand meteors before school started that fall. From that year forward, each June the nearest street lamp was shot out with a BB gun. (The city never got around to replacing the bulb until the next fall and I had dark skies all summer.) I saw more than a thousand meteors every summer, focusing intently on the area of sky known as the Square of Pegasus.

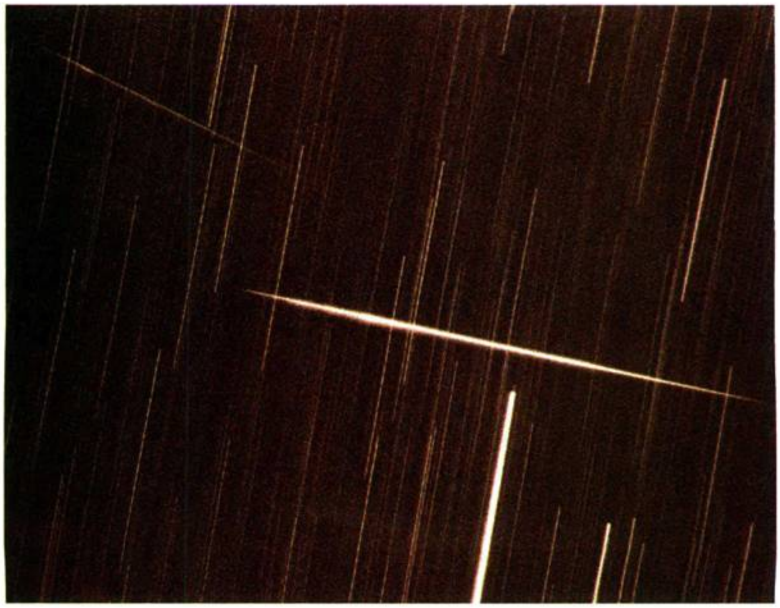
In 1951, I bought a Brownie Hawkeye box camera. I photographed star trails night after night but could never capture a meteor. In 1954, I moved up to an Argus C-3, bought used for $20. With its 50mm f/3.5 lens, I finally photographed a meteor in the summer of 1955 and sent it to *Sky & Telescope*, where it was published. I'd gone big time! Each year I kept observing, kept taking pictures, and kept improving.

After studying astronomy at Ohio State University, I

Perseids Peak

WALLY PACHOLKA

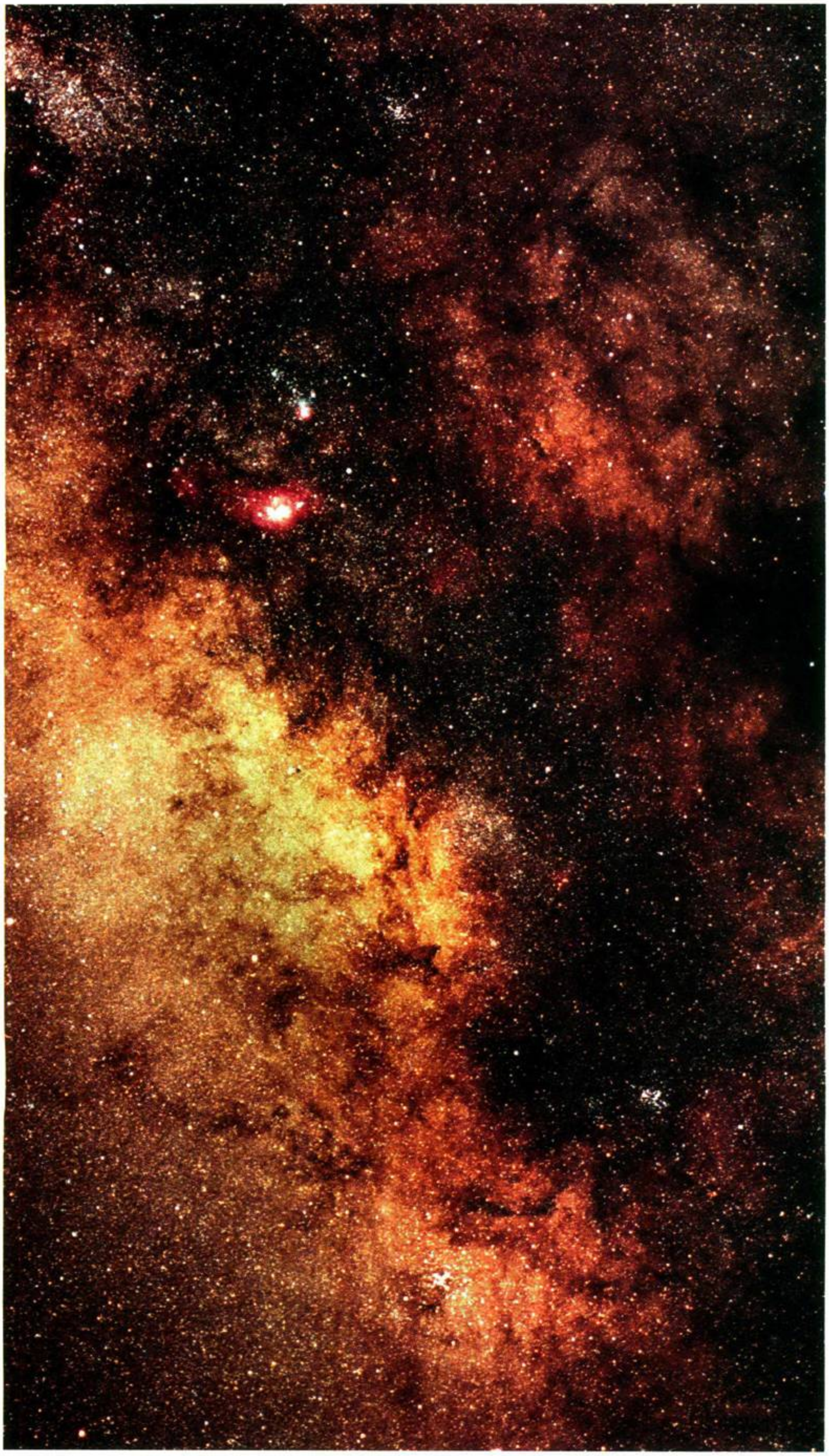
(50mm lens at f/1.7, Fuji 800 film, 20-second exposure taken August 12, 1997)



Geminid Fireball

HAL POVENMIRE

(35mm lens at f/1.2, Kodak 2475 recording film, 15-minute exposure taken December 12, 1989)



The Milky Way in Sagittarius

CHRIS COOK

(150mm lens at f/4, medium format camera, unhypered Kodak PPF 400 film, 25-minute exposure)

went to Cape Canaveral to start my career in astronautics in 1960. I worked on Project Mercury and used my meteor photography experience to photograph rocket launches. It was a great experience, but it became clear that I needed more education. I returned to Ohio State — all the while continuing to observe and photograph meteor showers.

In 1963, while photographing the Square of Pegasus, I saw a –7.0 Perseid light up the sky. Though I thought I'd missed the field, I developed the film and found I'd caught the end of the terminal burst. To this day, it's the brightest of 40,000 Perseids that I've observed.

In the early 60s, I began teaching high school science. I steadily acquired newer and faster cameras and began to introduce my students to the magic of meteor watching. I'd meet students in the football field and photograph meteors with the howls of coyotes echoing in the distance. Not many meteors were caught on these nights, but one roll of film contained a spectacular fireball, one that has since been published in many books. It must have occured behind my back, caught by one of my cameras and not my eye.

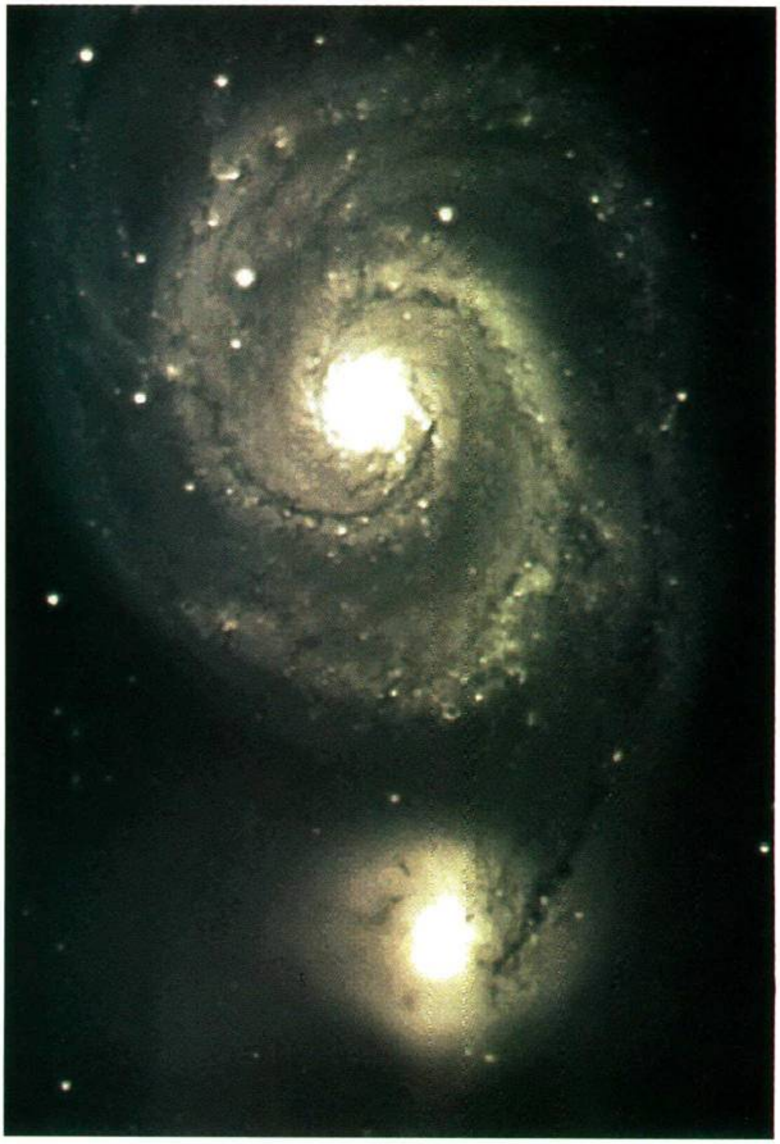
In 1969, I found myself working at the U.S. Naval Observatory in Washington, D.C. To observe the Perseids one evening, I left the observatory and headed toward darker skies, following no particular road. I traveled a number of miles to a dark wooded area, where I set up observation from the hood of my car. Almost immediately, Army jeeps had me surrounded with soldiers training their machine guns on me. Of all places to set up, I'd stumbled onto Camp David. At their request, I promptly moved a few miles away.

In June 1973, I traveled to Africa for a total eclipse of the sun. While onboard the HMS *Canberra*, I heard lots of lectures and got really excited about astronomy. I spent every night upon my return outside meteor observing. On August 18 at 9:46 p.m. I turned around to find a slow-moving, magnitude –14.0 fireball crossing the sky from south to north. As I held a star atlas up to the sky, the sonic boom hit and knocked the book back in my face. It seemed clear that meteorites must have fallen from this fireball, though I was never able to discover any.

I began paying as much attention to meteorites and meteor craters as I'd previously paid to watching the sky. In 1982, my wife and I made a trip to the Odessa, Texas, meteor craters. Between what we found, what we traded for, and what we bought, we returned with 170 pounds of Odessa iron meteorites.

The past 50 years have been centered around meteors. I have exposed well over a mile of film photographing more than 2,000 meteors and eight fireballs. With my own eyes, I have seen 100,400 meteors to date. And I don't expect to stop anytime soon. I look at it this way: There's a whole lot of stuff out there on a collision course with Earth. When it collides, it's interesting. And I think the most exciting event is yet to come. I just want to be out there, flat on my back, watching and photographing it. ◼

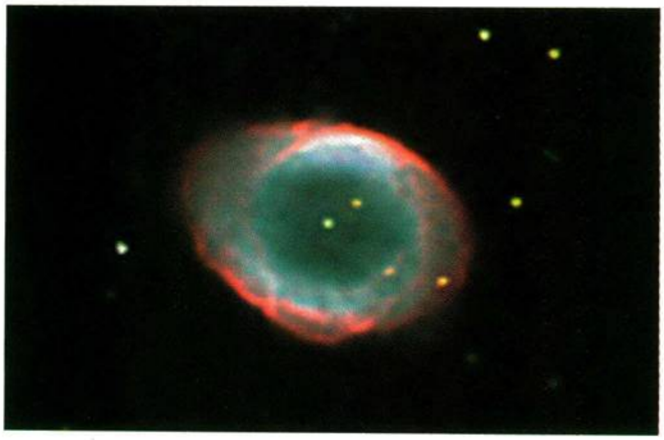
In addition to observing as many meteors as possible, Hal Povenmire works as the director of the Florida Fireball Network.



The Whirlpool Galaxy (M51) in Canes Venatici

JIM RIFFLE

(14-inch f/7 SCT, ST-7 CCD camera, composite of four 20-second exposures)



The Ring Nebula (M57)

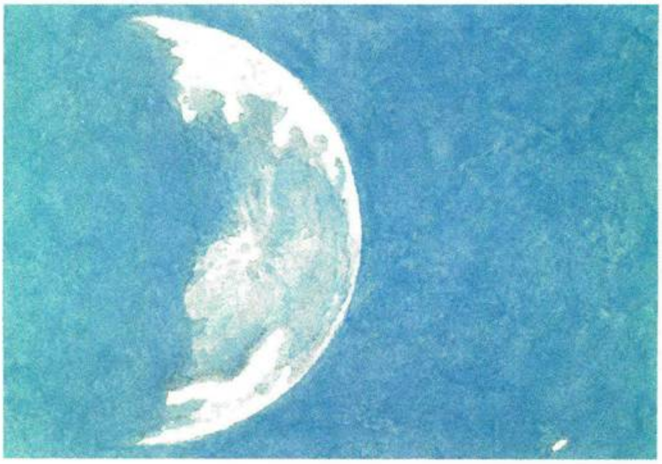
JACK NEWTON

(16-inch f/10 SCT, Pictor 1616XT CCD camera, composite of 5-minute red, 20-minute green, and 20-minute blue exposures)

Sol Sets

LARRY LANDOLFI

(500mm lens at f/4, Fuji Velvia film at ISO 50, 1/125-second exposure)



Lunar Rendezvous With Saturn in Daylight

JORGE IVAN CERRITOS

(Watercolor sketch of lunar conjunction with Saturn, 7x50 binoculars, June 28, 1997, 6 a.m. local time, Toronto)

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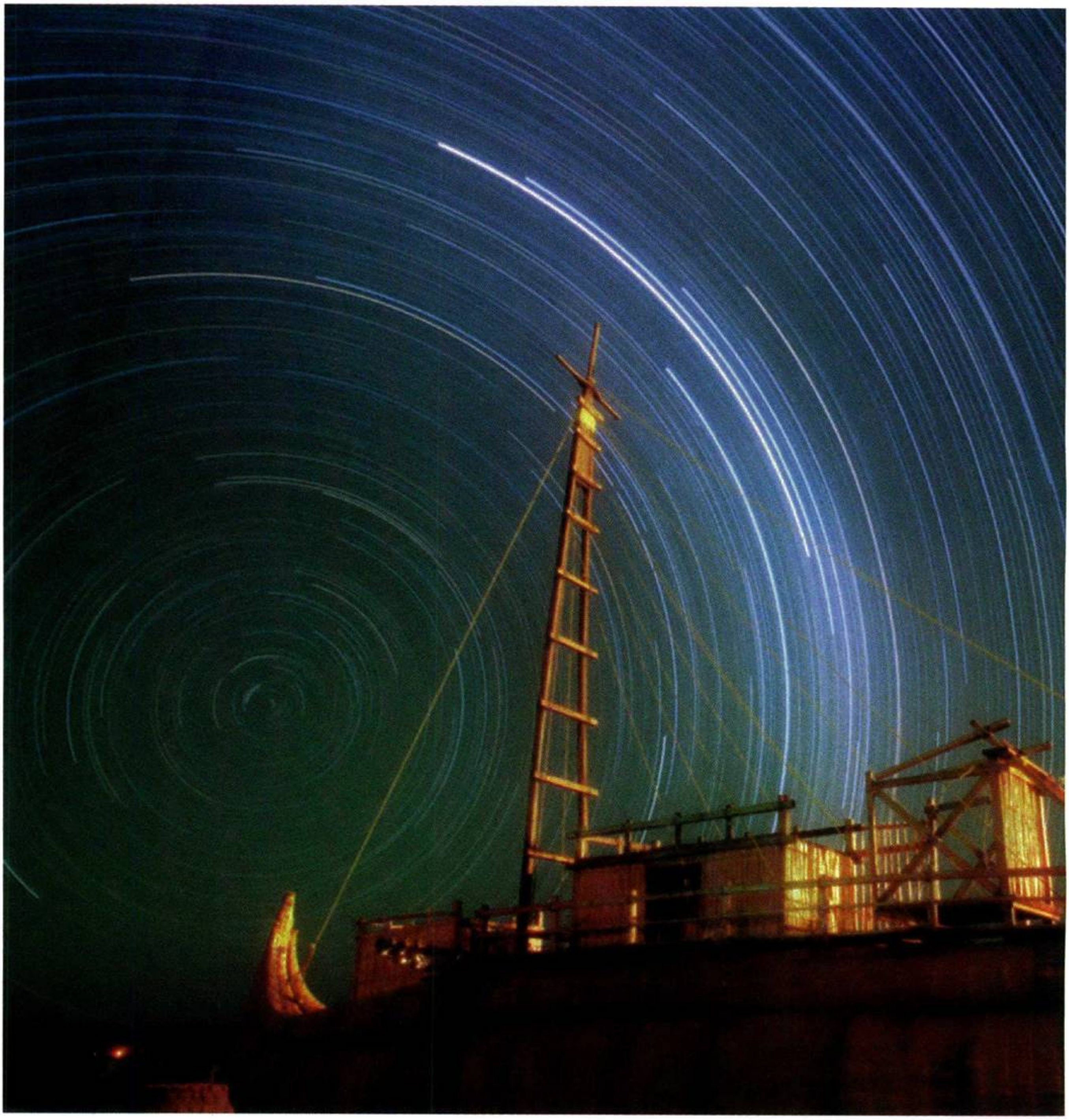

Setting Sail on the Southern Milky Way

VIC WINTER

(20mm lens at f/5.6, Fuji 100 film, 5-hour exposure taken July 2–3, 1997)

The southern summer Milky Way wheels behind a replica of Ra II, a reed boat sailed by Dr. Thor Heyerdahl in the early 1970s. Docked on the shores of Lake Titicaca in Bolivia, the replica was built by one of Heyerdahl's Bolivian shipwrights who still lives at the lake. This long exposure was taken during the Southern Skies Star Party, held at the Inca Utama Resort near the small town of Huatajata, on the shores of Lake Titicaca.

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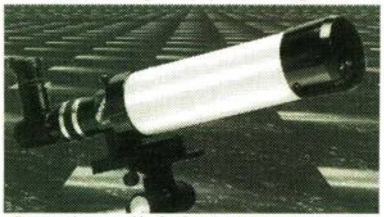

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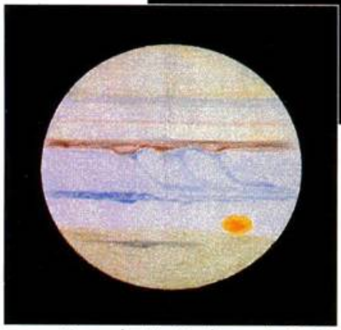
Dear Mr. Nagler,

"I thought it long overdue that I write to give my impressions of your Nagler eyepiece designs. *I say 'long overdue,' because I bought my first Nagler (a 7mm) back in 1984. The reason for the purchase was that earlier that year I had invested in a Celestron C-11 and a 4" Fluorite, F/9 refractor. I thought that the stated objectives of the Nagler design — long eye-relief and a wide, highly corrected field of view, would exploit the full potential of a telescope with 2,800mm focal length, and the imaging capacities of a fine refractor. I was not disappointed. Soon after came the fantastic 9mm and 11mm Naglers and then the 4.8mm for the refractor.*

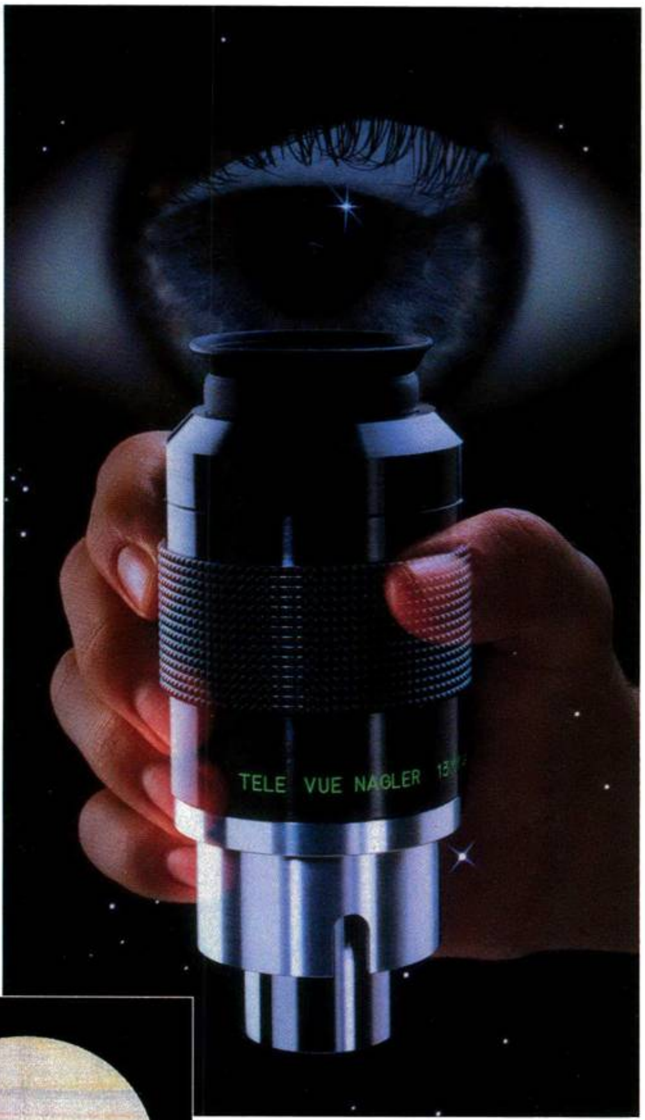
These eyepieces have given me my most rewarding hours spent at the telescope. *My main interest is in the planets which I draw and give lectures on at our local school and observatory. The observation of the planets requires painstaking hours spent at the eyepiece. The Naglers suit my purposes exactly.*

When the Type 2s were introduced onto the market I could not resist them. I purchased the 16mm and 12mm models. The 20mm seemed too large, heavy and costly, so I left it alone. These were the same reasons for not buying the 13mm (apart from the fact that by then I owned a 12mm Type 2). However, earlier this year, after years of looking through other people's 13mm and 20mm Naglers, I finally decided to take the plunge myself. ***So now I own a full set of Naglers*** *(including the wonderful 11mm which despite many offers, I will not part with).*



Drawn by Mr. Toohey with 12 N2

When I remember what eyepieces for the amateur market were like before the introduction of the Naglers (like looking down a drain pipe, or 60° fields, with astigmatism and severe edge of field aberrations), ***it is clear that your designs have taken us a quantum leap forward. No other eyepieces, in the Naglers' range of focal lengths, satisfy me now.***



Many of my fellow planetary observers say that conventional field eyepieces are sufficient. In a way they are right; good Plössls, for example, produce superb images. However, I believe the extra eye-relief, the huge field of the Naglers, coupled with marvellous image correction and the impression that ***the telescope simply gets out of the way,*** *all add up to a delightful psychological difference when using the Naglers. One feels more involved, more present to what one is viewing.*

Over the years I have found that amateur astronomers can be fairly stubbourn people in somehow defending their choice of equipment. Next thing you know they upgrade what was once, in their view, the very best available. ***Only good products stand the test of time. For me, the Naglers are such a product.*** *Not only have they remained with me; I have kept buying more of them!*

To some extent, astronomy, and particularly amateur astronomy, is about emotion and the involvement of the imagination. ***I have to say that Nagler eyepieces have captured my imagination.*** *As well as giving pride of ownership, Naglers are immensely satisfying and a joy to use.*

The little instruction sheet that comes with the eyepieces says that you wish the user 'years of exciting viewing with these eyepieces, and welcome comments on your experiences with them.' So you asked for it. After a decade of superb images (many of which remain etched on my memory; most of which I have recorded on paper) I felt it timely to share my comments and to thank you for your contribution to amateur astronomy."

Yours Sincerely.

Christopher Toohey, Australia

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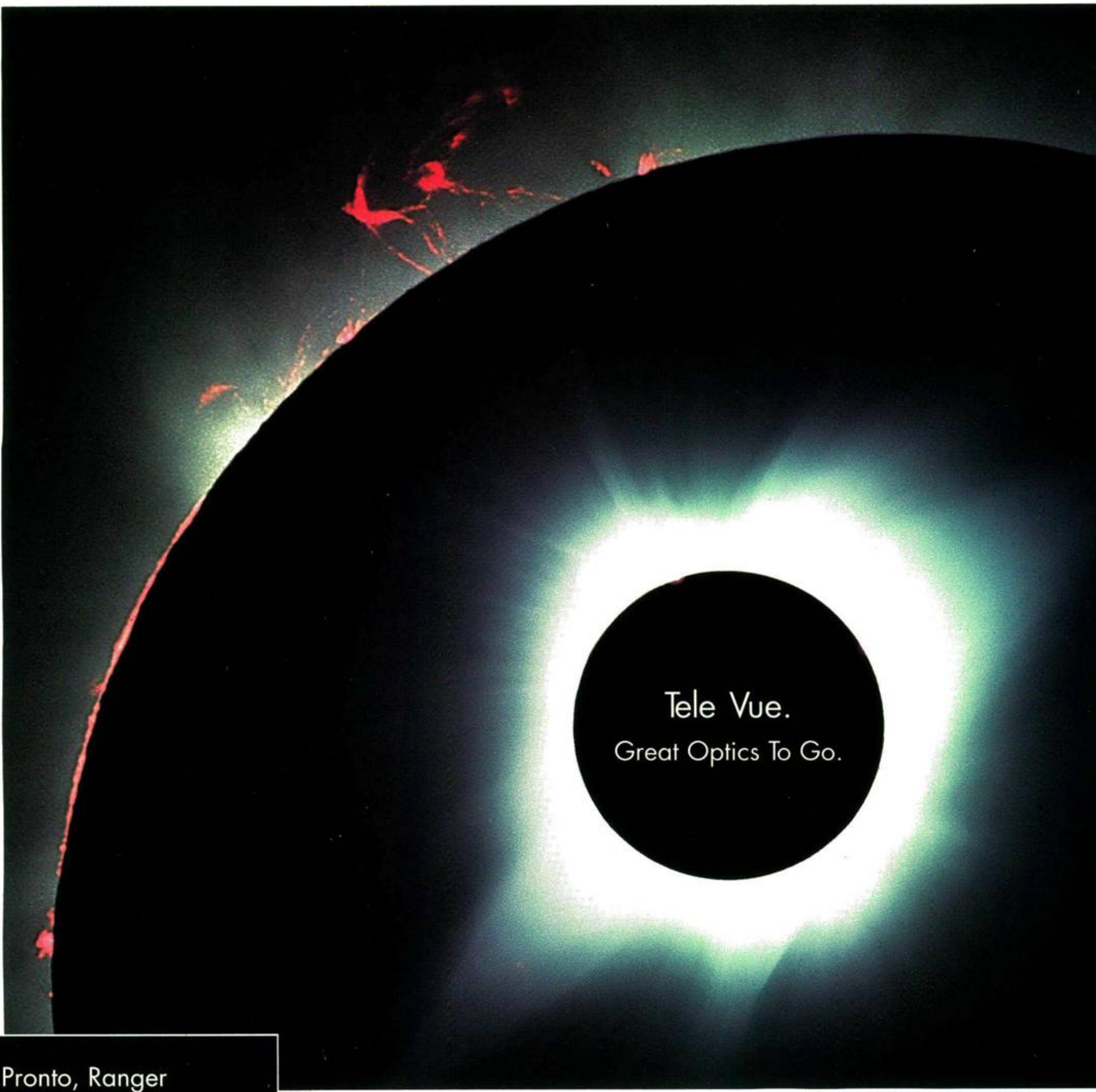

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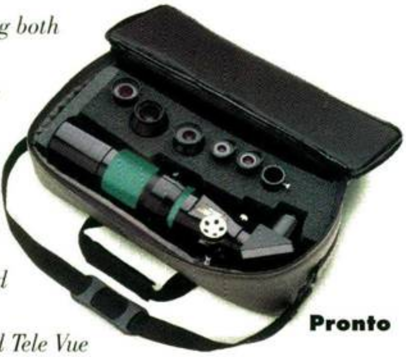

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